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HUGH MORRISTON DAVIES

Born August 10, 1879
An Eightieth Birthday Tribute

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THE DOYEN of thoracic surgeons in Britain, Hugh Morriston Davies, was born at Huntingdon, Cambridgeshire, eighty years ago, his father then being in medical practice in the town. This brief communication is intended for a tribute to him as an innovator and pioneer in the field of thoracic surgery and for achieving his professional eminence despite hazards that would have been the despair of lesser men. In the seclusion of the quiet Welsh village of Llanarmon-yn-Ial, he can now survey the years of his labors with serenity and a well-earned content. He is among the last of a privileged generation in British medicine, a select generation, which, recognizing in the early years of this century the inevitability of specialization, pursued its path with that eager devotion characteristic of pioneers.

He received his early education at Winchester College, proceeding to Trinity College, Cambridge, and to University College Hospital, London. In that golden era of medicine he had illustrious teachers, prominent among them Sir Victor Horsley, the neurosurgeon who later died in Mesopotamia in World War I. Morriston Davies's associations with University College Hospital continued following graduation; he became Horsley's surgical assistant, and, in 1907, he published a notable paper on the sensory changes in the face following

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Horsley's gasserian ganglion operation for trigeminal neuralgia. For this he was awarded the Cambridge M.D., having already become a Master of Surgery in his old university, as well as a Fellow of the Royal College of Surgeons. He and Wilfred Trotter now began to study the effects of nerve section on themselves, cutting the great auricular, the internal saphenous, and various cutaneous nerves of the arm. Trotter, then a young surgeon on the staff of University College Hospital, later became renowned not only for his surgical prowess but also for his trenchant contributions to philosophical and psychological studies.

At the age of 29, Morriston Davies was appointed to the surgical staff of the University College Hospital, and he then decided to devote particular attention to the diseases of the chest. He managed to obtain a research room in the basement of the medical school and was soon engaged on a study of pulmonary disease, using the new methods and techniques of radiology. In the very next room, Thomas Lewis was pioneering in electrocardiography. It was a period of great technological advance in medicine, and Morriston Davies was in the vanguard of the new clinical science. Hardly anyone in Britain had appreciated the potential value of x-ray in the diagnosis of chest disease; indeed many were sceptical and suspicious of these technical changes in the practice of medicine. Some of his eminent colleagues were even derisive of his tentative excursions into chest radiography. Resolute in his endeavors, however, he did not allow obscurantist opinions to modify his purpose. An incident in 1912 did much to vindicate his sanguine confidence. In that year, a male patient suffering from bronchitis was sent to his department—as a test case for him and his new apparatus. Morriston Davies found a shadow, which he diagnosed as a tumor of the lung. Some of his colleagues would not accept this diagnosis, and it was with consternation that they learnt of Morriston Davies's intention to remove the tumor. Nevertheless the operation was completed—the first dissection lobectomy in the world for carcinoma of the lung. Soon afterward he performed a Wilms' thoracoplasty for tuberculosis and, the following year, the Sauerbruch paravertebral thoracoplasty, both new operations in Britain.

Morriston Davies was already well acquainted with the progress made by the Germans in the now rapidly expanding field of thoracic surgery. At a meeting of the Deutsche Geselschaft für Chirurgie in Berlin in 1910, he had seen the methods used by the German pioneers for rib mobilization, together with the various devices employed by them in open operations on the chest. He then devised his own "Überdruck" apparatus—generally known to his associates as "H.M.D.'s fire-engine." He invented a special tenotome for adhesion section, which he used under radiographic control—there were no thoracoscopes then; he pioneered in Britain the several methods of extrapleural pneumolysis.

This was an inspired and prolific period in Morriston Davies's life, and in those spacious and confident years before the outbreak of World War I, there were ample rewards for men of ambition and endeavor. Now an acknowledged leader in his particular province of surgery, his future success was assured;

he was still in his thirties. One night, however, in the second winter of the war, he experienced a personal disaster that was to change the course of his life, a tragedy that was as dramatic as it was catastrophic.

That night, in January, 1916, he was called to see a patient in the Victoria Park Hospital in London whom he found to be suffering from an empyema; immediate rib resection and drainage were required. As he was closing the chest he was handed a length of catgut which accidentally contained a sliver of glass; the glass pierced the skin of his right hand. The following morning the hand began to swell and became increasingly painful. It was now evident to him that the sepsis he had been treating the previous night had entered and infected his right hand. Suppuration supervened, and the advice of eminent colleagues was sought—physicians and surgeons. Sir Thomas Barlow pronounced his considered opinion; Sir Rickman Godlee urged him to have the arm amputated. Eventually it was left to Wilfred Trotter to incise the hand and forearm. Although the infection now subsided, the damage had been done. The hand was contracted, the fingers were rigidly flexed, distorted, useless.

Morriston Davies then made the hard but inevitable decision that his surgical career was at an end; it was a bitter decision, but it was firmly made. He, thereupon, resigned from University College Hospital, turning from the main stream of surgical practice to the quiet backwaters of the profession of medicine. The humdrum activities of medical boards then occupied his time for a while, but they had little to offer to a man of his adroit ability. As a doctor in a sanatorium on the outskirts of London he found his work to be a little more congenial, but it was still irksome and wanting in stimulus and inspiration to an eager and inquiring mind. He rejected advice to turn radiologist. His only desire was to leave London and find some suitable work in the peace of the countryside.

Just after the War, he learnt that a country sanatorium in North Wales was for sale and, in spite of doubts expressed by his friends, Trotter among them, he resolved to buy the property. This was the Vale of Clwyd Sanatorium near Ruthin, to which he moved in 1918. He had now found a new purpose and direction. The following year his book on thoracic surgery was published, and soon a steady stream of publications, mainly on the surgical management of pulmonary tuberculosis, issued from his pen. About 1921, he embarked again on major surgery, using a new left-handed technique; the fundamental flair was unchanged. Under his direction the Vale of Clwyd Sanatorium became a thoracic center of some import, attracting surgeons to it from all over the world. Morriston Davies was now consultant thoracic surgeon to all the Welsh chest hospitals, and later to similar hospitals in Cheshire and Lancashire. In 1933 he published his standard work on pulmonary tuberculosis; in 1935 he addressed the American Society of Thoracic Surgeons in New York.

By the middle of the 1930's he was an extremely busy man, applying himself to his professional duties with a quite remarkable vigor. His assistants were constantly amazed at the energy he possessed, an energy dedicated to the

service of thoracic surgery. He would be ready, to the consternation of some and the admiration of others, to embark on clinical discussion at late hours of the night, after an already hard day of operating and travelling. He seemed to be indefatigable and, in his somewhat elfin appearance, there persists to this day some little intimation of immortality!

He had set his sights high, and he was intolerant of the slipshod and lazy; to the careless he was a hard master. He knew well enough that his own example was the standard, and the success of his endeavors rested on unremitting vigilance. He organized co-operation and teamwork, sometimes by force of will, often by force of character.

At the outbreak of World War II, he concerned himself with special arrangements for military and civilian chest casualties. In 1942 he was responsible in part for the publication, *War Injuries of the Chest.* The Liverpool and North-West Chest Unit flourished under his guidance as chief thoracic surgeon; he was also consultant thoracic surgeon to the Navy and Royal Air Force. In appreciation of his services to the city of Liverpool, the university there honored him with the degree of Master of Surgery. In 1954, the Royal College of Physicians awarded him the Weber-Parkes Prize with the citation "for the prevention and care of tuberculosis."

Morriston Davies is now, by chronological standards, an old man, but his vivacity and robust agility belie it. Logical in thought, wise in counsel, he still contributes readily to surgical debate; but, as he himself puts it, he now operates through the more nimble hands of another generation. He is spare and somewhat stooping in build, with a suggestion of defiance and even of pugnacity about his bearing. Age has wearied neither his resolution nor his ranging curiosity, and that indomitable spirit that once enabled him to triumph splendidly in adversity is fully manifest today. This man walked through a valley of shadows that few experience in this life, but anguish gave him new impetus and tribulation a new purpose. It is for that, and for his manifold contributions to the art and science of thoracic surgery, that we, in admiration, do him honor.

PRESIDENTIAL ADDRESS
CHANGING CONCEPTS IN THORACIC VASCULAR SURGERY

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MY FIRST thought at this time is to express my sincere and grateful appreciation for the signal honor which you have accorded me as President of this Association. After observing the list of distinguished men who have preceded me on these occasions, my pleasure in receiving this honor is exceeded only by my sense of humility. My next thought is to express my deep gratitude to the other officers of the Association, particularly our Secretary, Dr. Langston, and our executive assistant, Miss Hanvey, who have performed their duties with such diligence and efficiency that mine required little more than occasional concurrence and courteous attention.

In the selection of an appropriate topic for this occasion it seemed to me that, first, it should be sufficiently challenging to merit your attention and, second, it should be related to an area of work in which I have had intensive interest. During the past decade my associates and I have devoted our main efforts and attention to surgical approaches to certain cardiovascular problems. Among these, I have been especially concerned with diseases of the aorta and major arteries, and particularly aneurysmal and occlusive lesions. Accordingly, I should like to discuss some of the more significant observations derived from our experience during this period as they pertain particularly to conceptual and technical developments as well as to factors having an important bearing upon successful application of the operative procedure.

In general, the primary objectives of therapy have been removal of the lesion and restoration of vascular continuity. With increasing experience, however, certain modifications in this concept of surgical treatment have evolved, depending largely upon the nature of the disease. In aneurysms, for example, extirpation of the lesion or its complete obliteration is essential. In some instances this may be accomplished by complete excision of the diseased segment, whereas in other instances this purpose may be achieved with greater technical facility by partial excision and endoaneurysmorrhaphy. In occlusive diseases, on the other hand, removal of the lesion is not always essential and indeed in some instances is even undesirable. Under these circumstances the major problem is concerned with the hemodynamic disturbances produced by

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the occlusive process, whether it is of congenital origin, such as in coarctation, or of acquired origin, as in atherosclerosis. Accordingly, the primary objective of therapy in these conditions is correction of the hemodynamic disturbances and restoration of normal circulation. This may be readily achieved by means of the bypass graft without removal of the occlusive lesion, thus

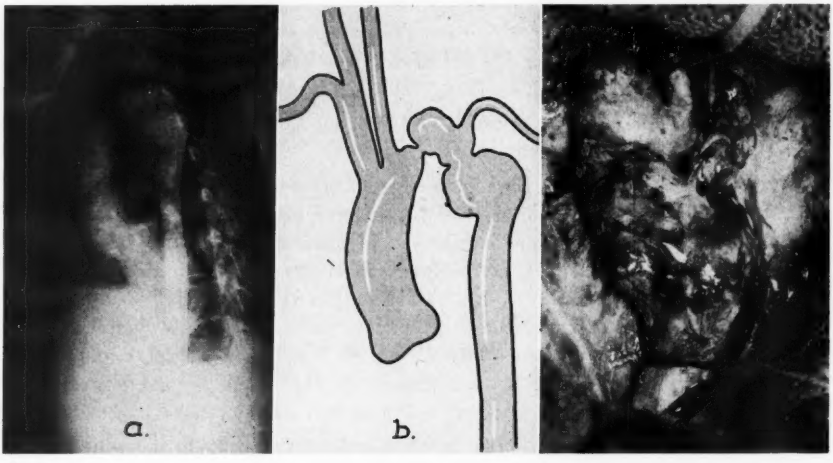

Fig. 1.—*a*, Preoperative angiocardiogram of patient with coarctation of aorta associated with aneurysmal formation, as depicted in *b* drawing. *c*, Photograph made at operation following exposure and immediately before resection of lesion.

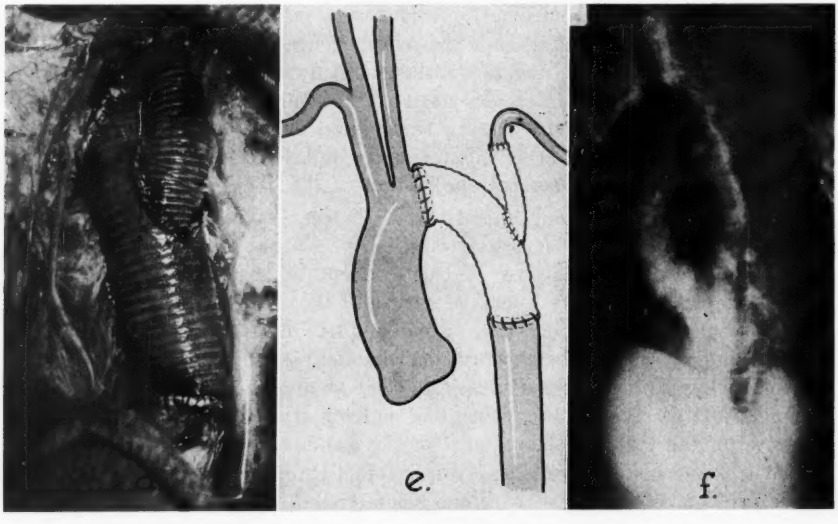

Fig. 1.—Cont'd. *d*, Photograph made at operation showing completed replacement of resected segment of coarctation and aneurysm of aorta with knitted crimped Dacron "graft," as depicted in *e* drawing. *f*, Angiocardiogram in same patient made about 2 months after operation showing normal restoration of vascular continuity and function.

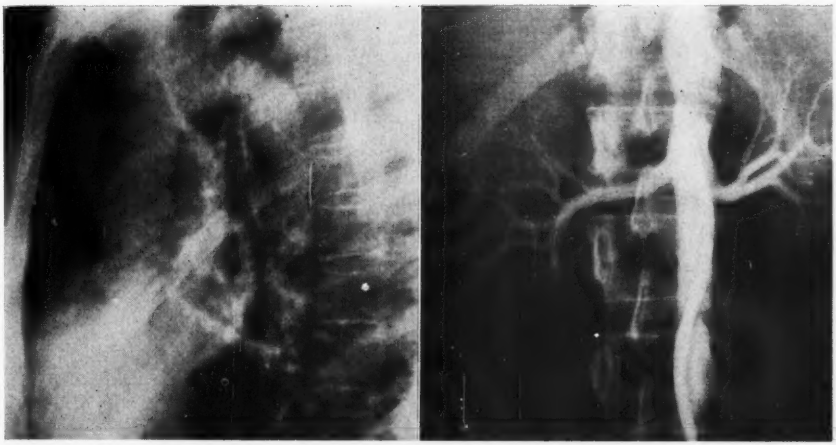

Fig. 2*A*.—Preoperative angiocardiogram and retrograde aortogram in patient with coarctation involving lower descending thoracic and upper abdominal aorta with marked calcification of latter segment.

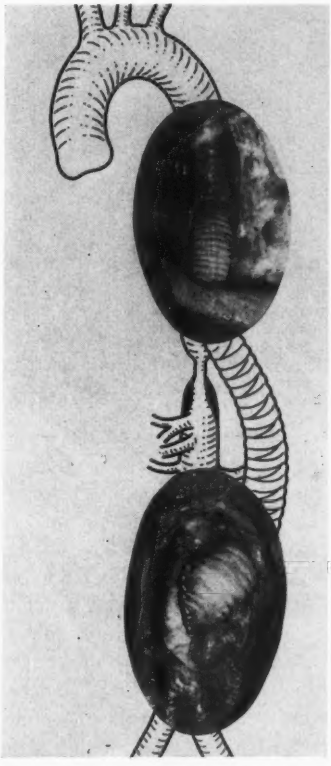

Fig. 2*B*.—Photographs made at operation with drawings in same patient illustrating application of bypass principle in patient with coarctation of aorta involving lower descending and upper abdominal aorta. The knitted crimped Dacron graft has been attached by end-to-side anastomosis to descending thoracic aorta above coarctation and similarly to abdominal aorta below coarctation.

avoiding some of the difficulties and hazards associated with excision and graft replacement. To be sure, extirpation of the coarcted segment with end-to-end anastomosis or with graft replacement is preferable in most of the usual forms of coarctation and should always be done in those associated with aneurysmal formation (Fig. 1). But in some of the more unusual types, particularly those associated with relatively long coarcted segments extending in some instances into the abdominal aorta, the use of the bypass graft principle has proved to be an entirely effective and much simpler technical procedure (Fig. 2). Similarly, in occlusive lesions involving the major

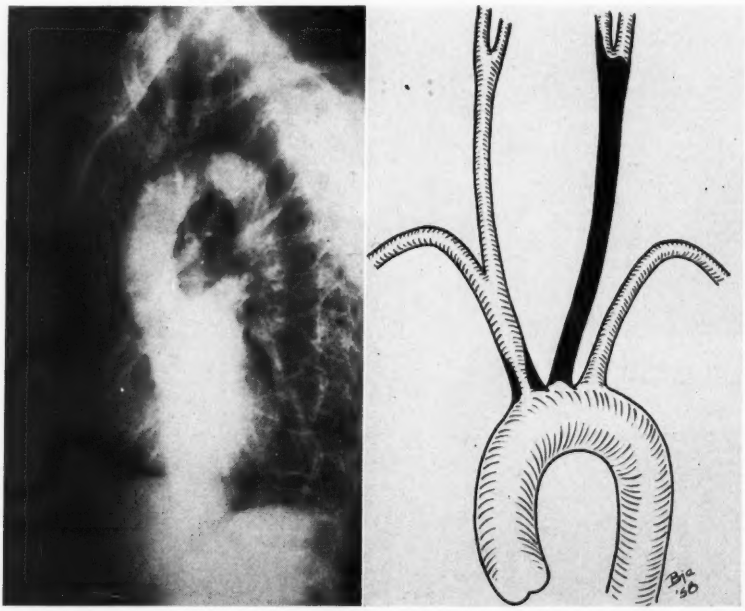

Fig. 3*A*.—Angiocardiogram in patient with atherosclerotic occlusive disease of major branches of aortic arch showing incomplete occlusion of innominate artery and complete occlusion of left common carotid artery, as depicted in drawing at right.

branches of the aortic arch, most of which are of atherosclerotic origin, the bypass graft principle has proved to be the most satisfactory procedure in most cases (Fig. 3). In a small proportion of these cases, in which the occlusive process is well localized and involves only one of these vessels, thromboendarterectomy may be the preferable procedure.

The most important consideration in the application of excisional therapy for aneurysms of the thoracic aorta is concerned with the necessity for temporary arrest of aortic circulation through the segment to be resected. The potentially hazardous consequences of this procedure are increased vascular resistance upon the heart with left ventricular strain and ischemic damage to the tissues distal to the occlusion, most important of which are the central nervous system and the kidneys. In general, this problem assumes increasing

significance as the level of occlusion becomes closer to the heart. Control of these factors, therefore, is of vital importance. Several methods may be used for this purpose depending upon the nature, extent, and location of the aneurysm. Among these, hypothermia was first used but, because of certain disadvantages associated with its application, it has been replaced by other methods which have been found superior. For most aortic aneurysms in which the proximal occluding clamp may be applied distal to the left common carotid artery, the most satisfactory method in our experience consists in the

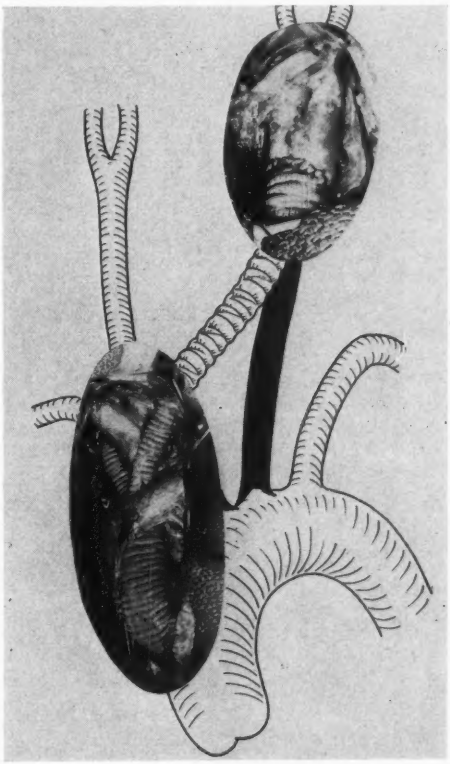

Fig. 3*B*.—Photograph in same patient made at operation with drawing illustrating application of bypass principle. The bifurcation Dacron "graft" has been attached by end-to-side anastomosis to ascending aorta, and in a similar manner the right limb of the graft has been attached to the right subclavian artery while the left limb of the graft has been anastomosed end-to-end to the endarterectomized distal opening of the left common carotid artery just below the bifurcation.

use of a pump bypass in which oxygenated blood is removed from the left auricle and pumped into the aorta distal to the occluding clamps through a plastic cannula inserted upward into the left femoral artery (Fig. 4). The major advantages of this method lie in the fact that it provides adequate circulation distal to the level of aortic occlusion to permit viability and even function, as reflected by renal function studies during this period, and to

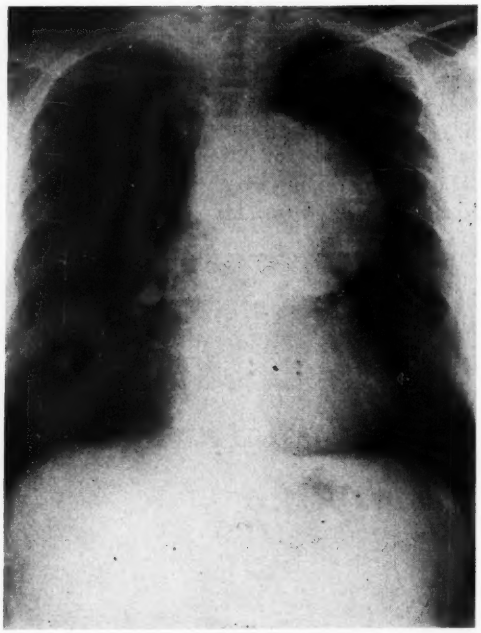

Fig. 4*A*.—Preoperative roentgenogram of chest in patient with large fusiform aneurysm of descending thoracic aorta.

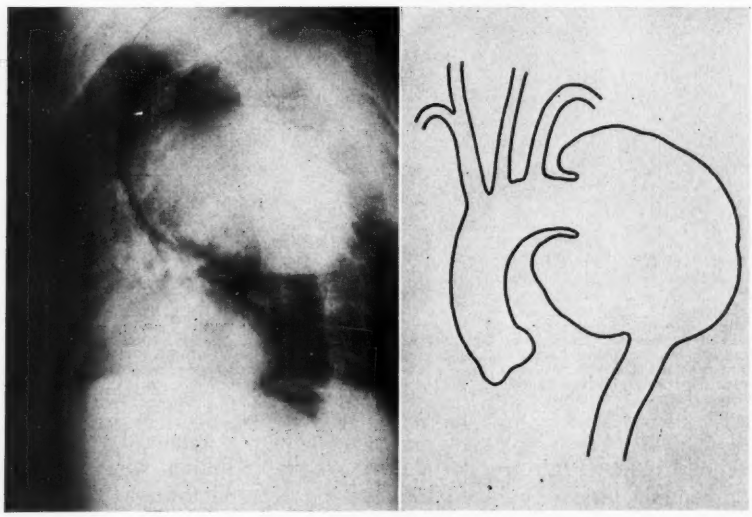

Fig. 4*B*.—Angiocardiogram in same patient showing location and extent of lesion, as depicted in drawing at right.

Fig. 4*C*.—Photograph made at operation showing completed replacement of excised segment of aorta and aneurysm with knitted crimped Dacron "graft."

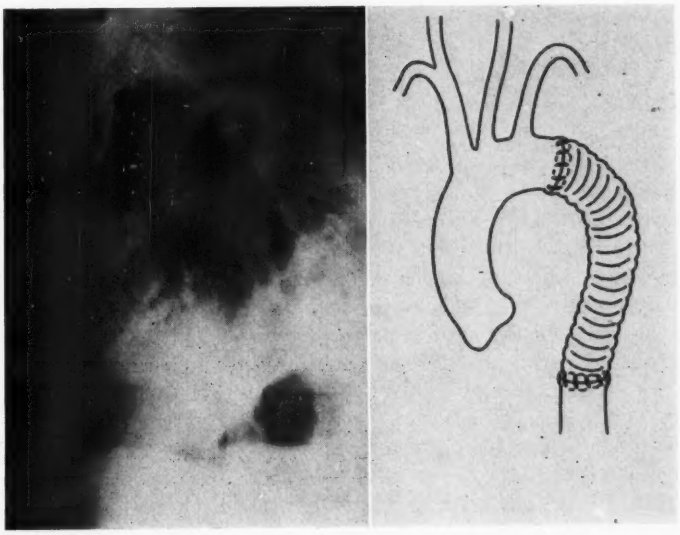

Fig. 4*D*.—Angiocardiogram in same patient made after operation showing relatively normal vascular continuity and function as depicted in drawing at right.

prevent serious left ventricular strain by maintenance of blood pressure at near normal levels. Although this method has been found to be the most satisfactory for aneurysms located in this region, it is not completely effective in preventing spinal cord damage, since among our 55 patients in whom this method was used, some manifestations of this complication occurred in 2. In this connection, it should be noted that in our earlier experience with hypothermia a somewhat similar incidence of the occurrence of this complication was encountered. This remains a rather baffling problem, as it has not been possible to correlate the occurrence of the complication with any significant

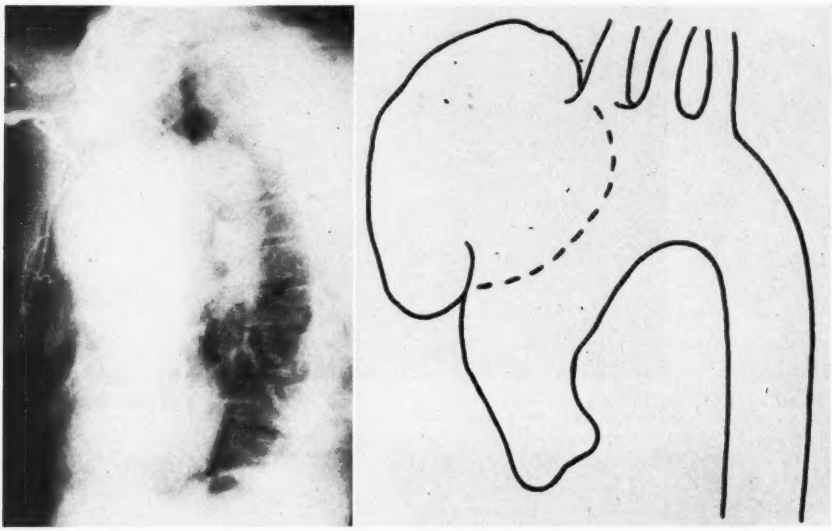

Fig. 5*A* —Angioaortogram of patient with large sacciform aneurysm involving ascending aorta as depicted in drawing at right.

factors, such as duration of occlusion, extent of resected segment, or pump bypass flow rates. For these reasons, along with other observations, we are inclined to believe that the more significant factors pertaining to this problem include variations in the anatomic pattern and segmental distribution of spinal arteries and development of collateral circulation.

Aneurysms involving the aortic arch that are located proximal to the level of the left common carotid artery are associated with much more difficult and hazardous problems, since arrest of aortic circulation at this level, even for a few minutes, may produce fatal heart failure or ischemic damage to the brain. Only in a few cases of sacciform aneurysms with a relatively narrow neck are these problems avoided, since they may be treated by tangential excision and aortorrhaphy. In all fusiform aneurysms, however, and even in sacciform aneurysms with a relatively wide neck that encroaches upon more than half the aortic circumference, measures must be taken to overcome the serious consequences of temporary arrest of aortic circulation at this level. Our experience with several methods which have been used for this purpose

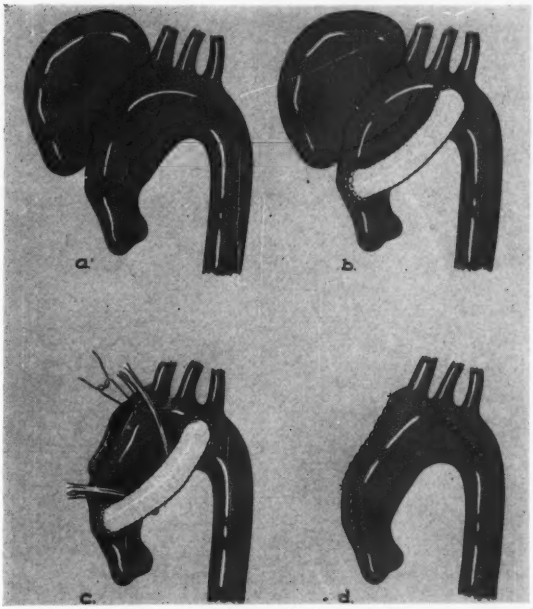

Fig. 5*B*.—Drawings illustrating surgical method of treatment employed in this patient utilizing temporary bypass graft to maintain aortic circulation during resection of aneurysm and repair by aortorrhaphy.

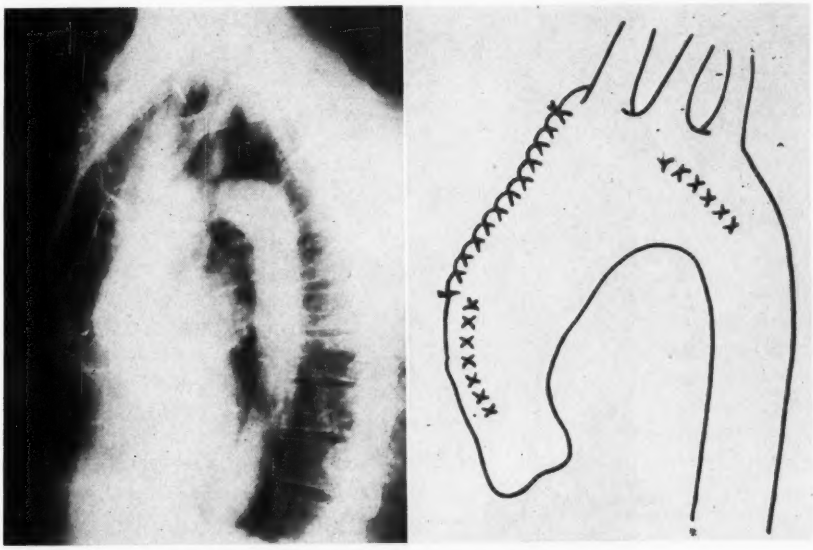

Fig. 5*C*.—Postoperative angiocardiogram in same patient showing relatively normal aortic continuity and function as depicted in drawing at right.

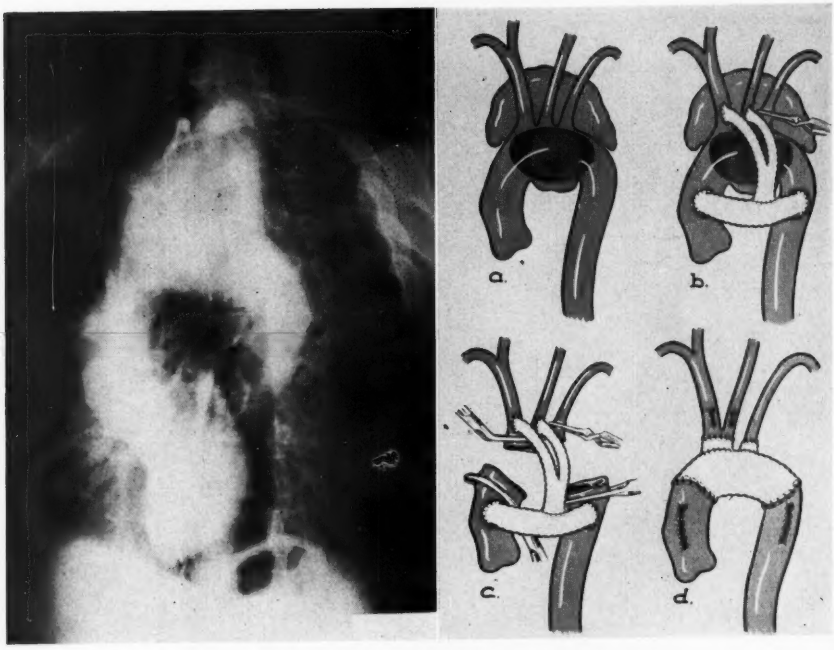

Fig. 6*A*.

Fig. 6*B*.

Figs. 6*A* and 6*B*.—*For legends see opposite page.*

would suggest that the critical determining factor in their application is the proximal extent of the aneurysm. Accordingly, the major factor in determining the method to be employed is dependent upon whether or not the aneurysm involves the proximal 3 or 4 cm. of the ascending aorta. Thus, in patients without involvement of this segment of the ascending aorta, the temporary bypass principle is employed. By this means and with the use of partial

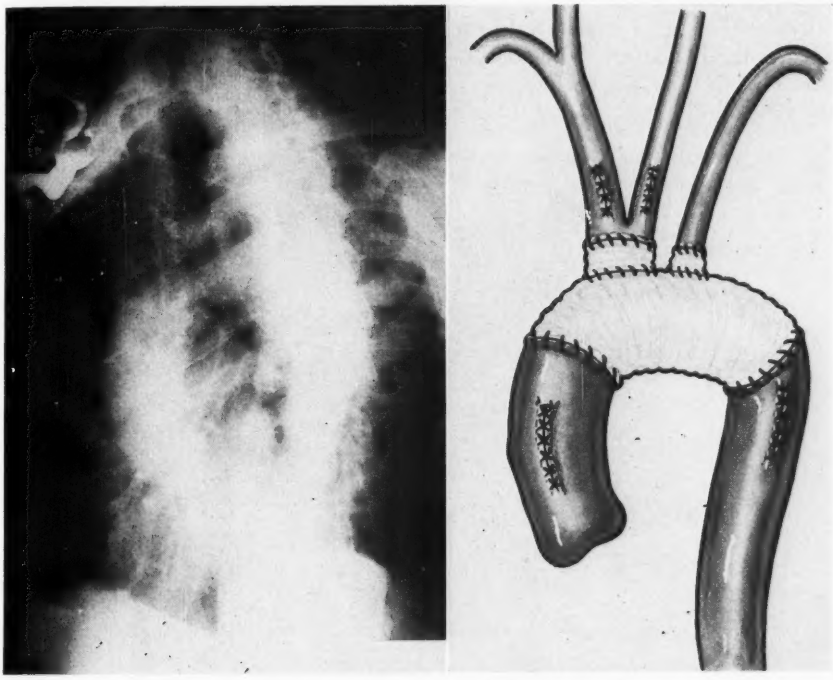

Fig. 6*C*.—Postoperative angiocardiogram in same patient showing relatively normal aortic vascular continuity and function in replaced segment of aortic arch as depicted in drawing at right.

occlusion clamps and end-to-side anastomosis, the bypass graft may be readily applied proximal and distal to the aneurysm after which the aortic segment to be removed may be isolated from the circulation with maintenance of relatively normal aortic circulation during the entire procedure (Fig. 5). In patients in whom the innominate and left common carotid arteries are also involved, appropriate branches from the bypass graft are extended to these vessels to provide cerebral circulation (Fig. 6). In this connection two technical principles have been evolved which have enhanced the simplicity and

Fig. 6*A*.—Preoperative angioaortogram showing large fusiform aneurysm involving aortic arch as depicted in drawing (*a*) at right. Drawings (*b*, *c*, and *d*) show method of surgical treatment employed in this patient utilizing temporary bypass Dacron graft to maintain aortic and carotid circulation during resection of aneurysm.

Fig. 6*B*.—Photograph made at operation showing completed replacement of excised segment of aortic arch and aneurysm with Dacron graft including anastomoses to innominate, left common carotid, and left subclavian arteries.

facility of the operative procedure. The first is concerned with the application of the bypass graft to the carotid arteries. In some cases, performance of end-to-side anastomosis on these vessels by use of a partial occluding clamp is technically difficult or may be associated with sufficient narrowing of the lumen to interfere significantly with cerebral circulation. These difficulties may be readily overcome with the use of the temporary internal shunt principle (Fig. 7). This can be easily done by use of a No. 14 soft polyethylene tube, approximately 10 cm. in length, which can be inserted through an opening in the artery in the same manner as a T-tube is inserted into the common bile duct, after which the artery is circumferentially tightened against the tube by means of umbilical tapes which had previously been looped around

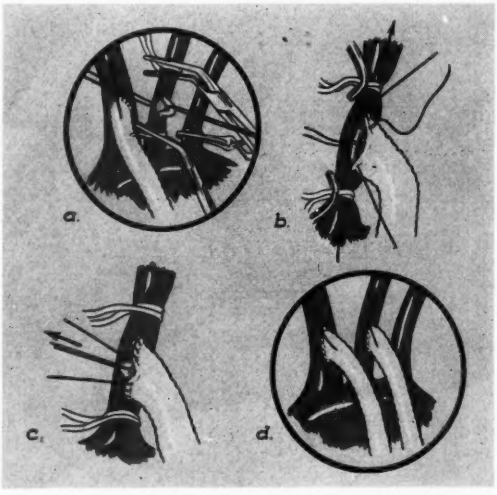

Fig. 7.—Drawings illustrating use of internal shunt principle to maintain circulation in carotid artery during end-to-side anastomosis of graft.

the vessels. While circulation is maintained through this polyethylene tube, the end-to-side anastomosis of the graft to the linear incision in the artery is performed and, just before the last few anastomotic sutures are tightened, the tube is quickly removed and the anastomotic sutures are tightened and tied. By this means cerebral circulation is interrupted for only a matter of seconds.

The second principle is concerned with conversion of the temporary bypass graft into the permanent graft. This has become possible with the development of the Dacron tube as a vascular replacement, which may be used as a temporary bypass graft as well as a graft replacement for the excised aortic segment. Although it is not always necessary or desirable to convert the temporary shunt into the permanent graft, under some circumstances it may have a distinct advantage in reducing the extent of the operation, particularly in cases in which the major branches of the aortic arch are involved in the procedure. Its further advantages will be discussed later in consideration of more extensive aneurysms involving both the thoracic and abdominal aorta.

Aneurysms that involve the proximal segment of the ascending aorta constitute by far the most serious and challenging problems in this field of surgery. Under these circumstances it becomes necessary to employ the cardiopulmonary bypass method with use of the artificial heart-lung apparatus. Application of this method imposes certain additional problems some of which have yet to be satisfactorily solved. For one thing, many of these patients are in the sixth to eighth decades of life and are likely to have varying degrees of associated heart disease. Temporary interruption or even decrease in coronary circulation in such patients is poorly tolerated and fatal heart failure may ensue. Second, owing to the necessity for heparinization in application of this method, control of hemorrhage in the grafted segment after completion of the procedure may be extremely difficult, despite the use of measures to counteract heparinization. To be sure, some success has been

Fig. 8A.—Preoperative aortogram in patient with large fusiform aneurysm involving lower descending thoracic and upper abdominal aorta including major abdominal visceral branches of aorta as depicted in drawing at right.

achieved in application of this method, but an almost equal number of failures has occurred, resulting mainly from the aforementioned problems. It is thus apparent that this represents an area in which there is need for more clinical and experimental investigations, particularly in regard to improved methods of maintaining coronary artery perfusion.

Increasing experience in the surgical management of aortic aneurysms and in these various technical procedures has gradually permitted assumption of a more aggressive role in the application of excisional therapy for the more extensive lesions which were formerly considered inoperable. The limitations of this method of therapy have thus been steadily extended. Indeed, so far as the lesion itself is concerned, there are now few contraindications to resection. This is well exemplified by the successful application of this method

of treatment in patients having aneurysms involving the entire descending thoracic and upper segment of the abdominal aorta or the lower descending and entire abdominal aorta (Fig. 8). Similarly, patients with separate fusiform aneurysms of the thoracic and abdominal aorta have been successfully treated by this means (Fig. 9). In patients with such extensive aneurysms and particularly those involving the lower descending thoracic and upper segment of the abdominal aorta from which the vital branches of the abdominal viscera arise, the principle of subsequent conversion of the temporary bypass graft into the permanent graft has proved of inestimable value in the successful application of this method of therapy. The extent to which this

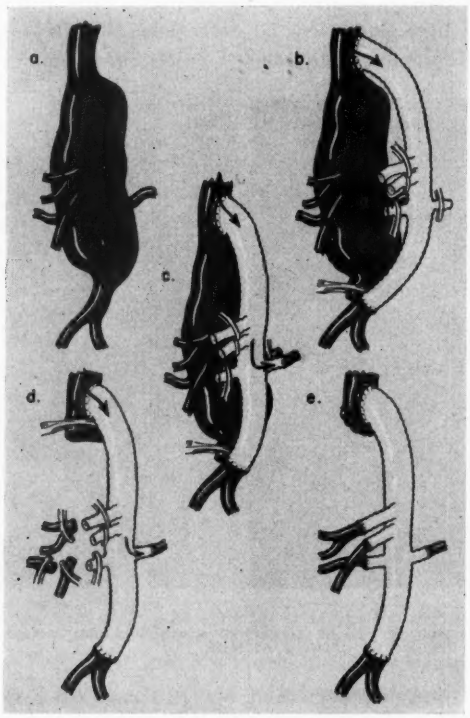

Fig. 8*B*.—Drawings illustrating method of resection and graft replacement in this patient utilizing principle of conversion of temporary shunt into permanent graft. An important advantage of this method lies in the fact that it minimizes the period of renal ischemia, which is the most critical factor in the operative procedure.

may be done is illustrated by a case of a huge dissecting aneurysm involving the descending thoracic and upper abdominal aorta which occupied virtually the entire left thoracic cavity (Fig. 10). The knitted Dacron bypass graft was attached by an end-to-side anastomosis to the aorta just distal to the left subclavian artery and then brought down through an opening in the diaphragm and retroperitoneally to be similarly attached to the abdominal aorta just below the renal arteries. With the graft serving as a temporary shunt, occluding clamps were applied to the aorta immediately above and below the aneurysm,

Fig. 8*C*.—Photograph made at operation in this patient showing completed replacement of resected segment of aorta with Dacron "graft" including branches to celiac, superior mesenteric, and renal arteries.

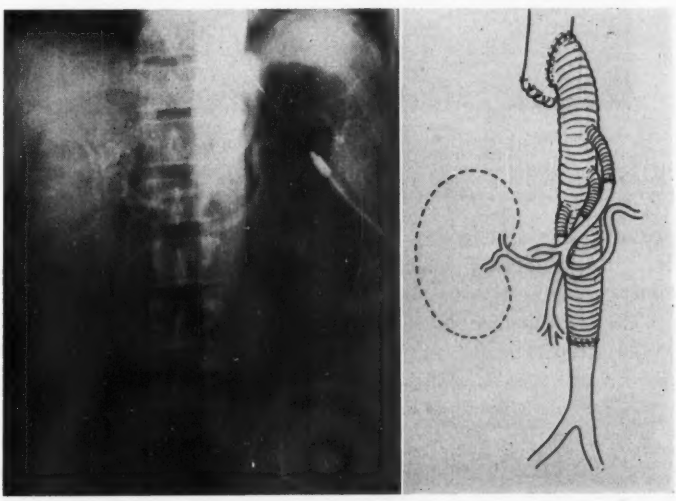

Fig. 8*D*.—Postoperative aortogram in same patient showing restoration of vascular continuity and function through Dacron graft as depicted in drawing at right.

thus isolating it from the circulation and permitting its excision. After completion of this procedure, the openings in the aorta adjacent to the occluding clamps were closed by suture and the occluding clamps were removed. The temporary bypass graft then remained to serve as the permanent graft. Since, during this entire procedure, there was no interference with aortic circulation, no hemodynamic disturbances occurred. Moreover, the extent of operative trauma, duration of anesthesia, and amount of blood lost were greatly minimized. These are factors which, from our experience, have assumed increasing importance in determining the patient's tolerance of the surgical procedure.

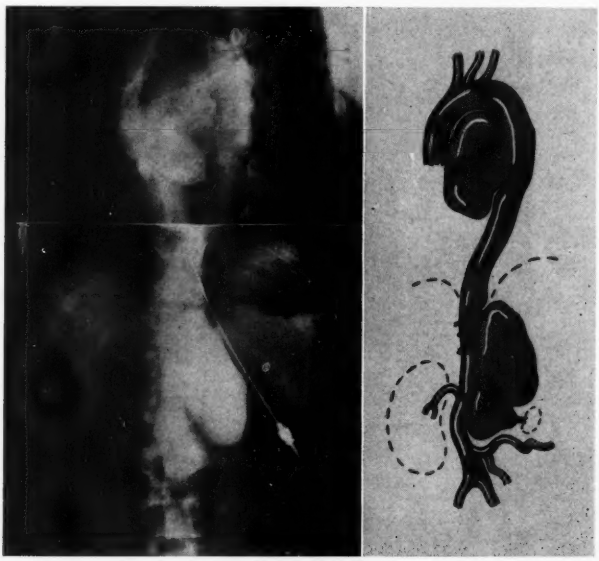

Fig. 9*A*.—Preoperative angiocardiogram and aortogram in patient with large fusiform aneurysm of upper descending thoracic aorta and another even larger fusiform aneurysm involving upper segment of abdominal aorta as depicted in drawing at right. Note that celiac, superior mesenteric, and left renal arteries are completely obliterated with compensatory collateral circulation being provided through enlarged inferior mesenteric artery.

There are, of course, a number of other factors, both systemic and local, which have an important bearing upon the risk of operation. Among the most important of these are advancing age, hypertension, and associated heart disease. The significance of age is well exemplified by the fact that the operative fatality rate for fusiform aneurysms of the descending thoracic

Fig. 9*B*.—Drawings illustrating methods of aneurysmal resection and graft replacement in this patient. The abdominal aneurysm was resected first, as illustrated by the upper three drawings, utilizing the principle of conversion of the temporary shunt into the permanent Dacron graft. On the fourth day following this operation the thoracic aneurysm ruptured necessitating emergency operation consisting of resection and Dacron graft replacement of the involved segment of descending thoracic aorta by the method shown in the lower left-hand drawing with pump bypass from left auricle to left femoral artery.

Fig. 9*C*.—Angioaortogram made approximately 1 month after operation showing restoration of aortic continuity and function through Dacron grafts in thoracic and abdominal aorta as depicted in drawing at right.

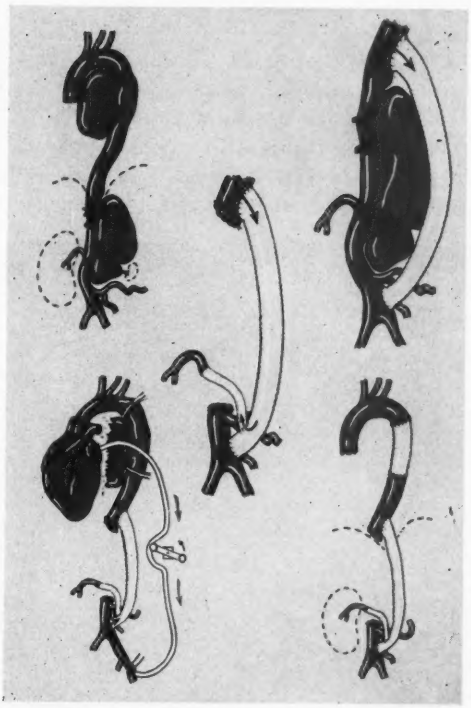

Fig. 9*B*.

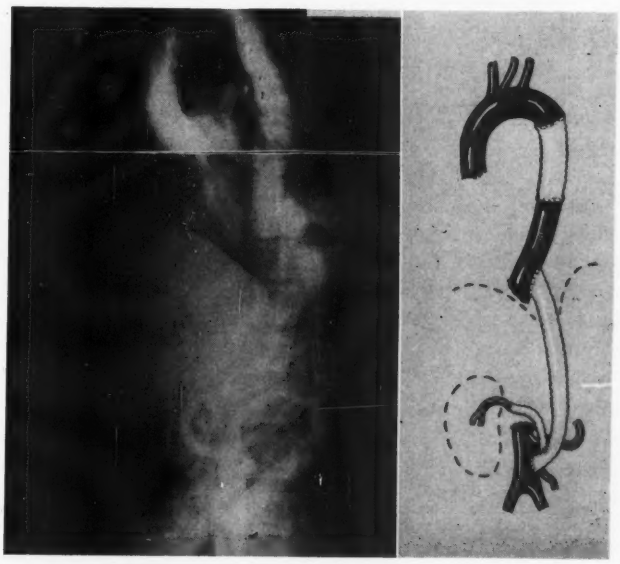

Fig. 9*C*.

Figs. 9*B* and 9*C*.—*For legends see opposite page.*

aorta was threefold greater in patients in the seventh and eighth decades of life than in those younger than this, the respective figures being 36 and 12 per cent. The importance of hypertension is demonstrated by the fact that the risk in this group of patients was almost three times greater than that in normotensive patients. Probably the most important factor in this regard is the presence of associated heart disease, particularly coronary artery disease, since in our experience the operative mortality in this group of patients was almost five times greater than that in patients without heart disease. There

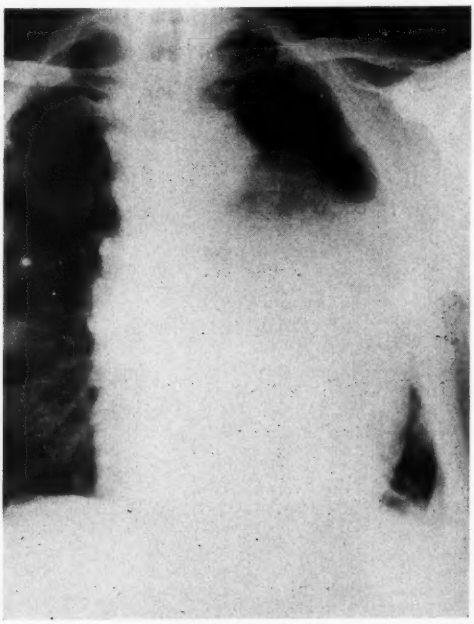

Fig. 10*A*.—Anteroposterior roentgenogram of patient showing large dissecting aneurysm of descending thoracic aorta occupying most of left pleural cavity.

is reason to believe, however, that despite these factors continued improvements in the surgical management of these patients should permit further reduction in the operative risk. This is indicated by the fact that in our most recent series of 62 cases of aneurysms of the descending thoracic aorta in which some of the technical developments just described were employed, the operative mortality was only 15 per cent which is exactly one half of that in our earlier series of 33 cases.

In addition to these tangible factors, which are concerned with the nature of the lesion and with associated local and systemic diseases, there are certain

Fig. 10*B*.—Aortogram of same patient showing extent of involvement of dissecting aneurysm arising just distal to left subclavian artery as depicted in drawing at right.

Fig. 10*C*.—Drawings illustrating method of surgical treatment employed in this patient utilizing the principle of conversion of temporary shunt into permanent graft as described in text.

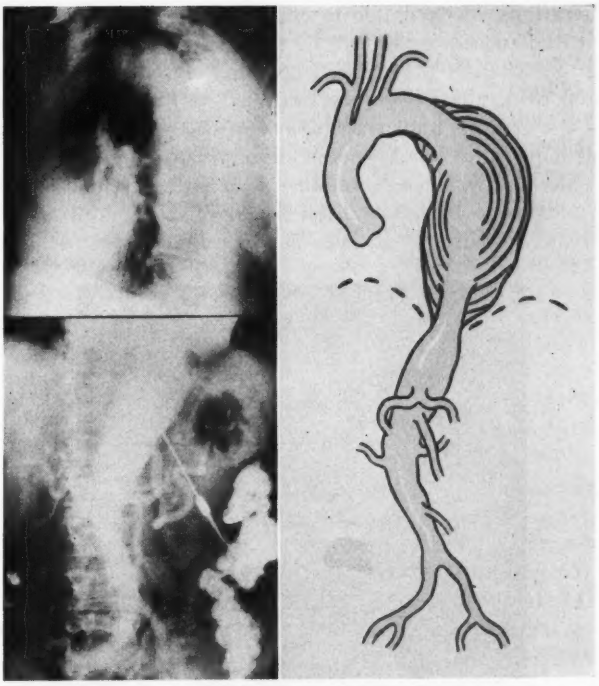

Fig. 10*B*.

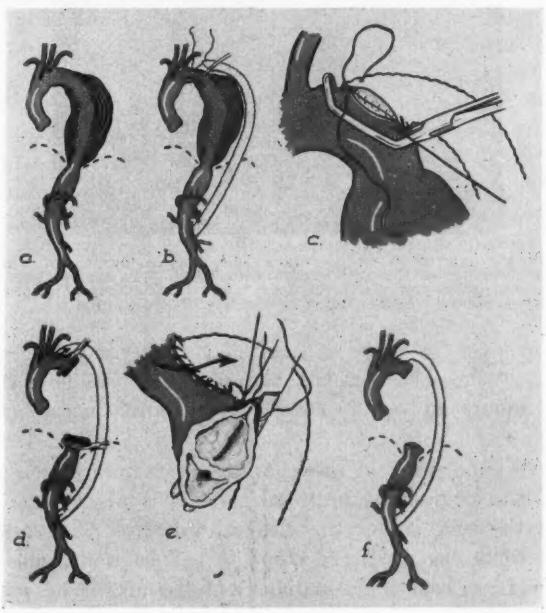

Fig. 10*C*.

Figs. 10*B* and 10*C*.—*For legends see opposite page.*

other considerations, less tangible in character, that also have an important bearing upon the success or failure of these methods of surgical treatment. They pertain particularly to surgical capability, extent of clinical experience, close attention to details, preciseness and dexterity in technical performance, and perhaps the attitude and temperament of the surgeon. To be sure, these are factors of importance in all types of surgery, but there is no field of surgery in which they assume as much significance as in cardiovascular surgery. This is due in large measure to the fact that the margin of safety in this field of surgery is often extremely small. Preciseness in dissection of tissues, in application

Fig. 10*D*.—Photograph made at operation following completion of procedure showing functioning thoracic portion of Dacron "graft" with end-to-side anastomosis of graft to descending limb of aortic arch just visible in upper right-hand corner of photograph. Most of abdominal portion of Dacron "graft" lies retroperitoneal.

of a suture, or even in tying a knot may make the difference between life and death. Technical errors which in some other fields of surgery would be considered minor can and do assume vital significance in cardiovascular surgery.

The relative importance of these intangible factors increases as a result of experience, and cognizance of these matters is of extreme value in the preparation of the surgeon for this field of surgery. The surgeon must be willing to put forth the necessary effort to perfect and refine his technical precision and skill in carrying out difficult procedures if he wishes to attain

the highest possible degree of success. Only by arduous attention to these details can he satisfactorily meet the difficult and challenging aspects of these problems. Still another factor, along these same lines that deserves emphasis, lies in the fact that cardiovascular surgery exemplifies so well the importance of fundamental training in general surgery. While one may consider this a highly specialized field of surgery, the need for thorough familiarity with the general field of surgery has been well illustrated by some of the cases to which reference has been made, in which the operative procedure was necessarily extended well beyond the thoracic cavity. Blood vessels have an inherent characteristic of reaching to all parts of the body and do not respect some of the artificial barriers which have been established by specialization. No less important are the various systemic problems of a physiologic or biochemical nature that are often associated with these vascular disturbances. Increasing experience in this field of surgery has led me, like others, to the firm conviction that successful surgical management, as well as progressive developments both conceptually and technically, is best expressed through a broad background in general surgery.

In conclusion, let me say that while the observations which I have presented here have been derived largely from our own experience, I am deeply appreciative of the pioneering efforts and the numerous contributions which have been made by a host of investigators throughout the world. Since many of them are present in the audience, it gives me much pleasure to express these sentiments of high tribute. The truly impressive progress that has taken place in the field of cardiovascular surgery during the past decade provides a brilliant reflection of these efforts. Among the most striking features of these advancements, and undoubtedly important factors underlying their attainment, have been the increasing intensity of research endeavors and the bold ingenuity and aggressive approach characterizing the surgical attack on these grave diseases. As a consequence, many conditions which only a few years ago were considered hopeless are now amenable to effective therapy. No less important has been the fact that these surgical investigations have contributed significantly to greater knowledge and better understanding of the underlying fundamental factors involved in the pathologic, physiologic, and biochemical disturbances of cardiovascular problems. With the continuing vigor and intense activity characterizing the current status of cardiovascular surgery, only the limits of imagination should restrict its progress.

VENA CAVA-PULMONARY ARTERY ANASTOMOSIS

III. Successful Operation in Case of Complete Transposition of Great Vessels With Interatrial Septal Defect and Pulmonary Stenosis

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Frederick H. Taylor, M.D., Charlotte, N. C.

IN PREVIOUS publications,[1, 2, 3] we reported our experiences gained in animal experiments with vena cava-pulmonary artery anastomosis. In these experiments, the superior caval vein was severed before entering the right atrium, the right pulmonary artery was transsected at its origin with the main pulmonary trunk, and the peripheral stumps of the two vessels were anastomosed by an end-to-end method. In this manner, about half of the systemic venous blood flow bypassed the right heart, and the right lung was supplied with blood directly from the superior vena cava.

Follow-up examinations, after 5 years, of the animals operated upon showed the pulmonary blood flow and oxygen uptake equal on both sides with no increase in venous blood pressure in the area of the superior vena cava. Similarly favorable experimental results were reported by Glenn and associates.[4, 5]

The vena cava-pulmonary anastomosis, as a palliative procedure, has the following advantages over other anastomotic operations: (1) no extra burden is placed on the heart by creating an artificial patent duct (on the contrary, it relieves the overloaded right ventricle of half of its output), (2) by decreasing the blood flow through the right ventricle, it decreases or completely abolishes the right-to-left shunt, (3) the blood pressure in the main trunk of the pulmonary artery is not elevated by this procedure, (4) the anastomosis supplies "pure" venous blood to the lung, providing 100 per cent oxygenation for nearly half of the systemic venous blood flow, (5) endarteritis is less likely to occur, and (6) technically the operation, even on small subjects, is not difficult.

On the basis of our animal experiments, in which the physiology of vena cava-pulmonary anastomosis was studied in detail, it seemed logical that this operation would be beneficial in some types of congenital cyanotic heart

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disease with normal pulmonary vascular resistance, such as tricuspid atresia or stenosis, Ebstein's disease, certain forms of Fallot's tetralogy, among others.

CASE REPORT

An 11-year-old white boy was admitted to the Department of Thoracic Surgery, Charlotte Memorial Hospital, because of retarded development and shortness of breath. On physical examination he was severely cyanotic, and the fingers and toes were clubbed. The apical impulse was in the left fifth interspace in the midclavicular line and it was forceful. There was a weak systolic thrill palpable over the whole precordium, and a systolic murmur with the same localization. The murmur was also audible in the epigastrium, over the aortic arch and carotid arteries. The maximum point of auscultation was parasternally in the left second and third interspaces. The pulmonary second sound was decreased in intensity.

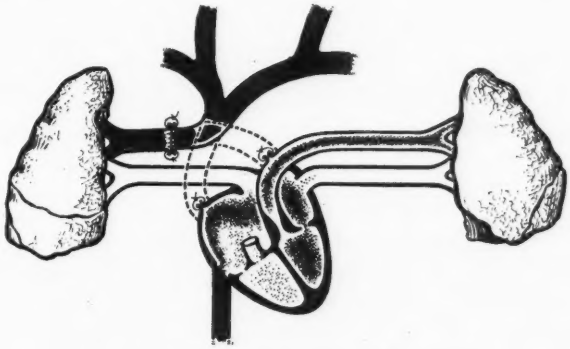


Fig. 1.—Schema of the operation performed.

The red blood cells numbered 5.5 million, hematocrit 54, hemoglobin 15.4 grams per cent; otherwise the routine laboratory data were irrelevant. The electrocardiogram showed right-sided heart strain. On x-ray examination, the heart was not enlarged. The pulmonary conus was not visible. However, the hilar vessels showed moderate enlargement and the peripheral lung fields were avascular. The mediastinum was narrow.

Right heart catheterization was performed through the prepared right saphenous vein. The catheter passed an interatrial septal defect and was later introduced into the right ventricle but not into the pulmonary artery. Blood pressure in the right ventricle was 98/3 mm. Hg. The oxygen content of the blood samples suggested a bidirectional (primarily, right-to-left) shunt at atrial level and a bidirectional (primarily, left-to-right) shunt at ventricular level.

Following the heart catheterization, an angiocardiography was performed. The dye-injection studies revealed a large interatrial communication, complete mixing of the blood in the ventricles, simultaneous filling of the retropositioned pulmonary artery, and the right-sided aortic arch.

With the aim of performing a complete repair of the heart condition, a thoracotomy was performed and an artificial heart-lung machine was held ready for cardiopulmonary bypass. The exploration revealed complete transposition of the great vessels. The small, hypoplastic pulmonary artery arose posteriorly from the left ventricle, and the outflow tract of the right ventricle continued directly in the dilated aorta. The condition was considered inoperable and the chest was closed without further attempts of correction.

The patient tolerated the procedure relatively well, but 4 to 5 months following surgery his condition showed further, rapid deterioration. The cyanosis increased and he became more and more dyspneic. At this time a second intervention (vena cava-pulmonary anastomosis) was decided upon.

Under endotracheal, ether-oxygen anesthesia, a right, posterolateral thoracotomy was performed in the bed of the resected fourth rib. The superior vena cava and the azygos

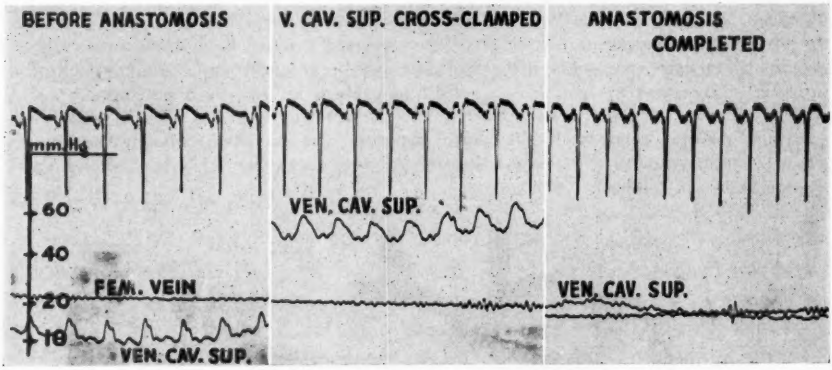
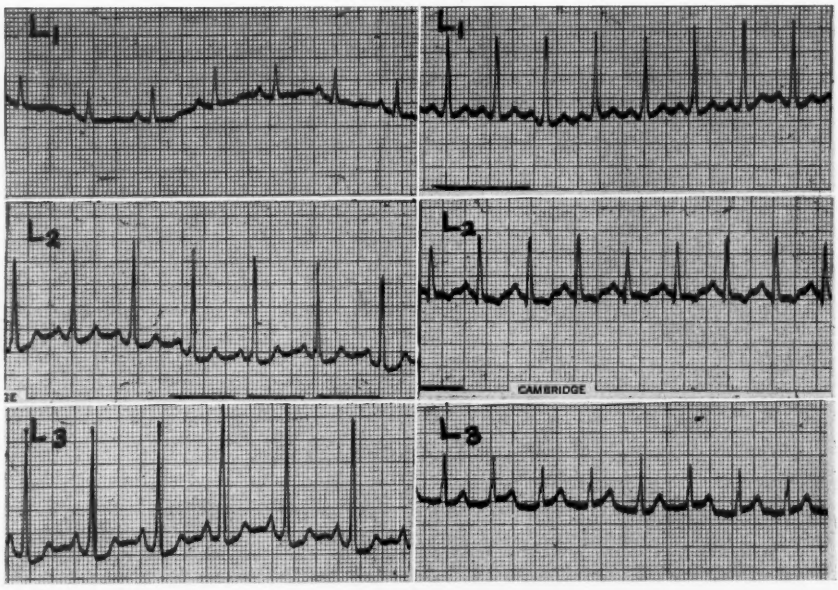


Fig. 2.—Intraoperative pressure tracings of the vena cava superior and femoral vein. (The tracings were taken with a pressure transducer levelled to the operative table, at the time the right pleural cavity was open.)



A. *B.*

Fig. 3.—Electrocardiogram taken before and 24 hours after surgery. Note the disappearance of right ventricular strain and rotation of the electric axis to the left. *A*, Before surgery. *B*, After surgery.

Fig. 4.—Preoperative angiocardiogram. Simultaneous filling of the right-sided aortic arch and pulmonary artery. Note the avascular lung fields.

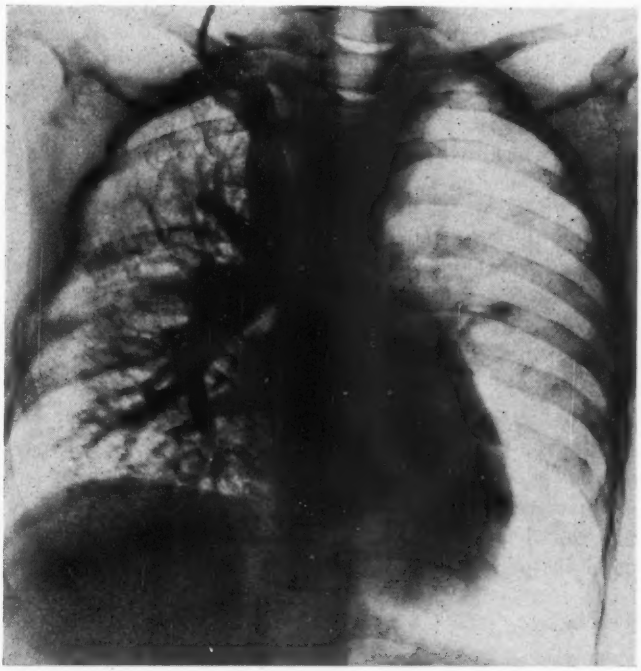


Fig. 5.—Postoperative angiocardiogram. The dye injected into the superior vena cava rapidly fills the vessels of the right lung through the wide vena cava-pulmonary anastomosis.

vein were dissected free. The pressures in the systemic venous system were continuously monitored by catheters inserted into the superior and inferior venae cavae. The pulmonary artery was localized rightward and posteriorly to the ascending aorta. The pressure in the pulmonary artery was found to be 16/7 mm. Hg. After freeing the right pulmonary artery, it was ligated at its origin with the main trunk and cross-sectioned distal to the ligature. The peripheral stump was held by a Crawford vascular clamp. Similarly, the superior vena cava was ligated before it entered the right atrium and was severed here. Thereafter, an end-to-end anastomosis was performed between the distal stumps of these two vessels. Upon releasing the clamps, the right pulmonary artery filled well through the anastomosis. The blood pressure in the superior vena cava at the time of the occlusion rose from 17/8 to 58/50 mm. Hg, but fell to 21/19 mm. Hg immediately after completion of the anastomosis. There was no change in the rhythm of the heart, systemic arterial, and inferior vena cava blood pressures. The cyanosis of the face and lips increased significantly during the occlusion of the superior vena cava, but completely disappeared following the anastomotic procedure. An intercostal tube was used to drain the right pleural cavity as the thoracotomy wound was closed in layers.

The patient awakened immediately after the operation and had an uneventful postoperative course. The cyanosis did not return even after moderate physical exercise, which he was able to do without dyspnea. The oxygen saturation of the systemic arterial blood rose from the preoperative 82 to 93 per cent. Angiocardiography, performed on the fourteenth postoperative day, showed rapid filling of the right pulmonary vascular system from the superior vena cava through a wide open anastomosis. An electrocardiogram made after surgery showed the disappearance of the right ventricular strain and the electric axis turned to the left.

The patient was discharged 14 days following surgery and has been followed closely since then. He has good color and no recurrent signs of cyanosis. Venous pressures are essentially normal and he is able to perform normal physical activities without dyspnea.

SUMMARY

After 5 years of animal experiments, the authors performed a vena cava-pulmonary anastomosis on an 11-year-old boy, suffering from complete transposition of the great vessels, interatrial septal defect, and pulmonary stenosis. In the course of the operation, the superior vena cava and right pulmonary artery were ligated proximally and cross-sectioned, and an end-to-end anastomosis was performed between the distal stumps of the vessels. In this way about 50 per cent of the systemic venous blood flow bypassed the right heart and was shunted directly into the right lung. The patient tolerated the procedure well and showed significant postoperative improvement.

The authors recommend the procedure for the treatment of congenital heart disease when pulmonary blood flow is impaired, pulmonary vascular resistance is not elevated, and complete surgical repair cannot be performed because of anatomic reasons or because of the patient's age or general condition (such as, tricuspid atresia and stenosis, hypoplasia of the right ventricle, atresia of the pulmonary artery, and certain forms of tetralogy of Fallot).

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SUPERIOR VENA CAVAL REPLACEMENT

IV. Experimental Use of Alcohol-Preserved Heterografts of Bovine Aorta

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THE IMPORTANCE of obtaining a suitable and consistently successful means of superior vena caval replacement and bypass has been discussed in detail in previous communications.[7, 8, 9] Synthetic vascular prostheses and homografts of aorta and vena cava have been shown to be unsuitable.[1, 2] Of the free grafts, only fresh autogenous aorta has been found to be consistently successful with long-term retention of patency and freedom from constriction and thrombus formation.

The present study was carried out to evaluate the suitability of alcohol-preserved heterografts of cow aorta for superior vena caval replacement.

MATERIAL AND METHODS

Healthy mongrel dogs were used. The weight of the dogs ranged from 12 to 30 Kg. A mixture of oxygen and ether, delivered through an endotracheal tube by means of a mechanical respirator, was employed for anesthesia following induction with intravenous Pentothal. A right third intercostal space thoracotomy incision was used. The superior vena cava was dissected free from surrounding structures. Potts coarctation clamps were used to occlude the proximal and distal ends of the superior vena cava and a portion of the superior vena cava was resected. The resected segment of vena cava was replaced with a preserved heterograft of cow aorta. A continuous over-and-over suture of 5-0 arterial silk was used for both anastomoses. The heterografts of bovine aorta were all slightly to significantly larger than the canine vena cava being replaced. The heterograft appeared to function satisfactorily in all animals at the time of placement. The cow aorta has a very thick and firm wall and there was no tendency for the heterograft to collapse. The chest wall was closed in layers and a catheter, which was left in the chest during the closure, was aspirated and withdrawn.

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The segments of cow aorta employed in this study were obtained from a local packing company and were preserved in 70 per cent ethyl alcohol. The duration of storage and preservation in alcohol ranged from 7 to 8 months. The heterografts were reconstituted for at least one hour in normal salt solution containing penicillin and streptomycin.

RESULTS

Alcohol-preserved heterografts of bovine aorta were employed as described for the replacement of resected segments of superior vena cava in 11 dogs. Heterograft patency was investigated by cavogram, postmortem examination, or both from 2 days to 18 months following caval replacement (Table I). The heterograft was found to be patent in 9 animals and occluded in 2. The 2 animals in which heterograft occlusion occurred were examined at autopsy 14 and 21 days after operation. The graft was patent in all of 7

Fig. 1.—Cavograms demonstrating patency of heterografts used for superior vena caval replacement (*A*) in Dog 847 and (*B*) in Dog 870, 18 months following operation.

dogs in which graft patency was investigated more than 30 days after operation. Two animals are alive 18 months after operation. Recent cavograms have established the patency of the heterografts in both animals (Fig. 1).

The gross appearance of the heterograft was studied at autopsy in 9 animals. In 2 of those studied, occlusion of the graft with thrombus formation has occurred. Neither heterograft constriction or thrombus formation was encountered in 4 dogs examined from 2 to 32 days following operation. A few thrombi were found at both suture lines in one animal, 31 days following operation. Nonetheless, this heterograft was patent and showed no evidence

TABLE I. SUMMARY OF EXPERIENCE WITH ALCOHOL-PRESERVED HETEROGRAFTS OF BOVINE AORTA FOR SUPERIOR VENA CAVAL REPLACEMENT IN DOGS

DOG NO.	WEIGHT (KG.)	PERIOD OF GRAFT PRESERVATION IN ALCOHOL (MONTHS)	INTERVAL, OPERATION TO LAST CAVOGRAM	GRAFT PATENCY AT LAST CAVOGRAM	INTERVAL, OPERATION TO AUTOPSY	GRAFT PATENCY AT AUTOPSY	REMARKS
837	12	8	15 days	Patent	31 days	Patent	Sacrificed; no constriction or thrombus formation
840	24	8			32 days	Patent	Died of pneumonia; no constriction or thrombus formation
841	19	7			31 days	Patent	Sacrificed; no constriction; a few thrombi at both suture lines
846	27	7	4 days	Patent	21 days	Occluded	Died with empyema
847	19	8	18 months	Patent			Alive 18 months following operation; cavograms 4 days, 18 days, 12 months, and 18 months after operation all revealed patency of heterograft
848	17	8	18 days	Patent	12 months	Patent	Sacrificed; graft widely patent without thrombus formation; limited area of confraction in one section of graft
858	30	8	14 days	Occluded	14 days	Occluded	Examined after cavogram; occluding thrombus appeared to have originated at level of distal anastomosis where there was some disparity in size
860	30	8	14 days	Patent	17 days	Patent	Died of pneumonia; no constriction or thrombus formation
869	30	8	5 days	Patent	8 months	Patent	Died of unknown cause; one area of constriction widely patent; no thrombus formation
870	27	8	18 months	Patent			Alive 18 months following operation and in good health; cavograms 12 and 18 months after operation revealed patency of heterograft
873	24	8			2 days	Patent	Died of hemothorax; graft widely patent; no constriction or thrombus formation

of constriction. The heterograft in Dog 869 was studied 8 months after placement. The graft was patent and free of thrombus formation. A degree of constriction was encountered in one area of the graft. Similar findings were observed in Dog 848, 12 months after heterograft placement (Fig. 2). The constriction which had occurred in one area of this graft had not significantly compromised the lumen of the graft. It is of interest that the calcification so often found in long-term devitalized, preserved homografts used for aterial replacement was not encountered in either of the 2 animals studied by autopsy, 8 and 12 months following operation.

Fig. 2.—Autopsy photograph of heterograft from Dog 848, 12 months after operation. A small area of constriction at one end of the graft may be seen.

Microscopic study of the homograft in Dog 848 was carried out 12 months after operation (Fig. 3). The graft wall was quite thick. The bulk of the graft wall was acellular and essentially amorphous. There was no significant invasion of the graft by surrounding connective tissue. No microscopic evidence of calcification or thrombus formation was encountered. The lumen of the graft had become endothelized.

DISCUSSION

Although alcohol-preserved heterografts of bovine aorta were not uniformly successful in the replacement of canine superior vena cava, their successful use in 9 of 11 animals is regarded as significant. Alcohol-preserved heterografts seem to differ from fresh heterografts and those preserved by the freeze-drying method. Kimoto and his associates[6] have suggested that this

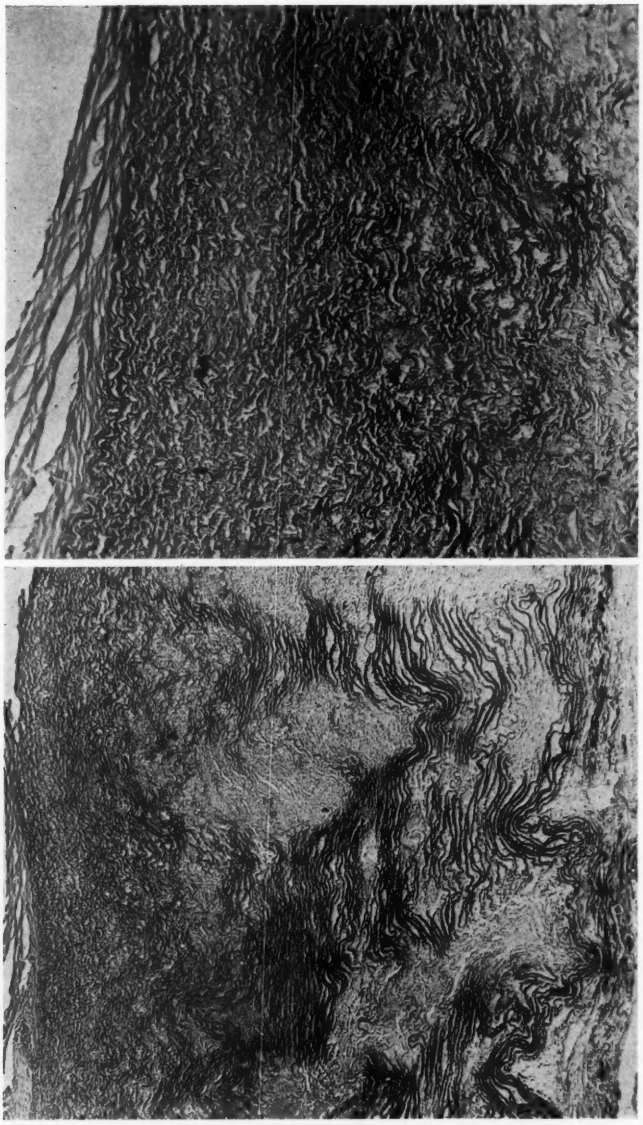

Fig. 3.—Photomicrographs, under low power (*left*) and higher power (*right*), which show thick, acellular, and relatively amorphous, heterograft wall, and absence of significant host connective tissue and vascular invasion in Dog 848, 12 months after operation.

difference might be due to the elimination of some of the untoward antigen-antibody reactions which occur in heterologous transplantation in the viable state. They felt that this alteration might be brought about by the action of alcohol in the dissociation of lipoproteins and the denaturization of other proteins rendering the heterograft serologically inert. They found that heterografts of human arterial segments of viable preservation were successful in replacement of resected segments of the abdominal aorta in only 3 of 8 dogs. When alcohol preservation of the heterografts was employed for periods ranging from 6 to 219 days, the heterograft remained patent in 19 of 21 animals. While rupture occurred in 4 of the 8 heterografts of viable preservation, it was not encountered in the group of 21 animals in which alcohol-preserved heterografts were utilized. The 2 failures in the group in which the alcohol-preserved grafts were used were due to thrombotic occlusion of the heterograft.

The thickness of the walls of the heterografts which rendered them essentially noncollapsible and the greater size of the lumen of the heterograft, than that of the superior vena caval segments they were being utilized to replace, are likely factors in the surprising success experienced with the use of alcohol-preserved heterografts for caval replacement in this study. The use of free grafts larger than the superior vena cava for caval replacement has not been reported. The long-term suitability of thick-walled or rigid free grafts for caval replacement also has not been investigated. Enerson and Galante[3] have reported short-term experiences of 1 to 5 weeks with semi-rigid free grafts of alcohol-preserved homografts which were externally supported by a braided nylon tube. The homograft was secured to the nylon tube with a few interrupted sutures of fine silk. A slightly greater short-term freedom from partial or complete thrombosis was observed in the group of externally supported homografts.

Graft constriction appeared to be a less serious problem with the larger, thick-walled bovine aorta heterografts than with the smaller, more thin-walled homografts. Gerbode[4, 5] found that all of 25 homografts used for superior vena caval replacement had become occluded within 8 months after placement by thrombosis or fibrotic constriction. Some constriction was observed in 2 heterografts, 8 and 12 months after operation. However, the degree of constriction in these larger, thick-walled heterografts did not significantly compromise the size of the graft lumen. It was also of interest that calcification was not encountered in either of these long-term grafts on postmortem study.

The results of this study would appear to justify a more detailed investigation of the suitability for superior vena caval replacement of alcohol-preserved heterografts of relatively large size and thick walls. In addition, the experimental use of some of the newer, more rigid, synthetic vascular prosthetic tubes, in sizes larger than the vena caval segment to be replaced, would seem to be indicated.

SUMMARY

The experimental use of alcohol-preserved heterografts of bovine aorta for superior vena caval replacement in 11 dogs is reported. The heterografts were preserved for 7 to 8 months in 70 per cent ethyl alcohol. The caval replacement was found to be successful, with retention of graft patency, in 9 of the animals and in all of 7 animals in which graft patency was investigated by cavogram, autopsy, or both, in excess of 30 days following operation. Heterograft patency was demonstrated in 2 living animals by cavogram 18 months after operation.

The role of alcohol preservation in enhancing the biologic usefulness of heterografts in vascular replacement is discussed. All of the heterografts were larger than the caval segments replaced and all had thick and relatively noncollapsible walls. The importance of these factors in successful caval replacement with preserved heterografts and the desirability of further studies are discussed.

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EXPERIMENTAL AND CLINICAL APPLICATION OF A PUMP FOR PARTIAL AND TOTAL AORTIC BYPASS

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A PUMP bypass which shunts blood from the left atrium to the femoral artery provides an excellent system for excision and replacement of the descending thoracic aorta. Our work, reported here, confirms that of De Bakey, Cooley and associates,[1, 5] who advocate this technique for managing certain aortic lesions. Our experiments also suggest that the left atrial-femoral artery shunt may provide a good solution to the formidable problem of resecting the aortic arch. This type of bypass for the aortic arch has been recommended recently by Johnson[8] and it would have the advantage of being much simpler than the use of a pump-oxygenator.[5]

Hypothermia,[6] vascular shunts without pumps,[4] and special anastomotic techniques[9, 10] have all been employed to permit resection of the thoracic aorta. These methods have serious disadvantages which the pump bypass largely overcomes. Although hypothermia may protect against spinal cord damage, it does not prevent the hypertension proximal to the site of aortic occlusion which puts a heavy burden on the left ventricle. It could not, of course, be used alone for aortic arch lesions. Vascular shunts from proximal to distal artery without a pump are troublesome, unreliable,[6] and difficult to arrange in the operative field. Special anastomotic techniques are hard to use and have only limited applicability.

A pump system for either partial or total aortic bypass which eliminates many of these difficulties has been studied in dogs and employed clinically for resection of the descending thoracic aorta.

METHODS AND MATERIALS

The pump utilized throughout the experiments was a modified Dale-Schuster[3] pump designed by Dr. M. Gliedman, who formerly worked with one of us. The pump (Fig. 1) consists of a flexible Gooch crucible tubing, with a capacity of 80 ml., enclosed in an airtight tube of Lucite. Alternate

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suction and compression is applied on the flexible tubing within the cylinder of Lucite and delivered through a three-way solenoid valve. Originally, a self-regulating mercury switch tripped by the distended tubing was used to regulate the duration of the phases of alternate compression and suction, but this was found to be unreliable. Therefore, it was replaced by a variable

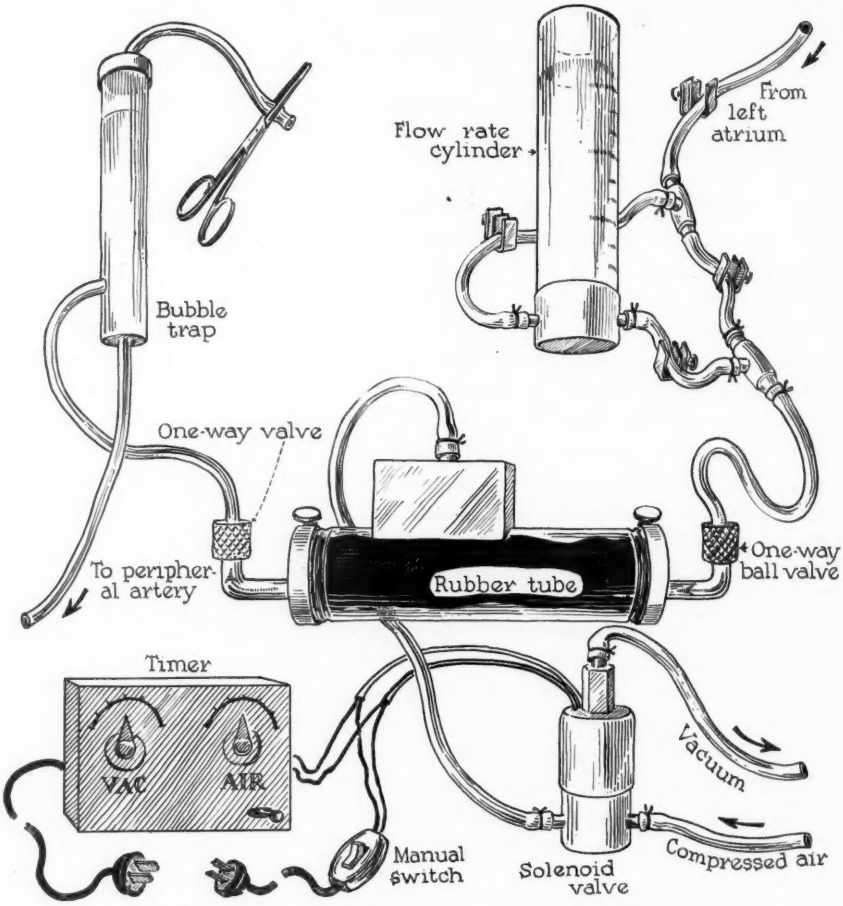

Fig. 1.—The pump used for the extracorporeal bypass.

electronic timer.* The direction of flow through the pump is regulated by the one-way ball valves. Blood flows into the Gooch tubing by gravity, assisted by external suction in the Lucite tube, and is ejected from the pump by compressed air replacing the suction. The volumetric capacity of the pump and the connecting tubes varied with the speed and duration of filling. It

*Obtained from G. C. Wilson & Co., Huntington, West Virginia.

varied between 20 and 55 ml. The rate of filling and pumping was adjusted between 14 and 26 times per minute to maintain an optimum flow in the individual experimental animal. For ideal conditions, it was deemed necessary for the filling phase of the pump to be on the average of one and a half times as long as the emptying phase.

Adult mongrel dogs were used throughout the experiments. Anesthesia was obtained with intravenous Nembutal. The femoral and right brachiocephalic arteries were isolated and the left pleural space was entered through the fourth interspace. Heparinization was obtained with 1.2 mg. per kilogram of weight. A No. 18 Fr. flexible plastic catheter was placed into the left atrium and connected to the inflow tubing of the pump and a No. 12 or 14 Fr. plastic Bardic catheter was placed into one of the femoral arteries and connected to the outflow tubing of the pump to complete the bypass. The flexible plastic catheters were found superior to the rather rigid polyethylene catheters of the same size.

In the series of partial aortic bypass, the descending aorta was occluded just below the arch and, for total aortic bypass, the ascending aorta was clamped above the coronary ostia. Distal arterial pressure was recorded by an arterial catheter inserted into the remaining femoral and connected to a mercury manometer. Proximal pressures were recorded by a catheter inserted in the brachiocephalic artery. When the ascending aorta was clamped in the total bypass, the pressure just above the aortic valve or in the left ventricle was recorded through a rigid No. 5 Fr. catheter introduced through the brachiocephalic artery and passed beyond the site of occlusion. Clamping of the aorta was not sufficient to occlude the lumen of this catheter, and reliable pressure readings were obtained.

The duration of the bypass varied from 30 minutes to 90 minutes. After completion of the procedure and removal of the catheters, protamine sulfate was given to neutralize the heparin. Penicillin was instilled into the pleural space before closure and given systemically for one week postoperatively.

Plasma hemoglobin determinations were performed before and at the completion of the experiment as a measurement of the extent of red blood cell destruction. At the time of death or late sacrifice of the experiment animals, histologic studies of the kidneys, liver, and other viscera were obtained.

RESULTS

After standardization of the technique of the bypass with an extracorporeal pump, 26 mongrel dogs comprised the experiment study group. Nineteen of these were subjected to partial aortic bypass and 7 were subjected to total aortic bypass.

Three of the 19 dogs undergoing partial bypass were lost because of technical error during the operative experiment. Only one of the 16 animals surviving the procedure succumbed in the early postoperative period, and this as a result of hemorrhage from the chest wall. The 15 remaining animals

were followed from 3 to 60 days and none of these revealed any neurologic disturbances as a result of the cross-clamping of the aorta. At the time of occlusion of the aorta, there was a temporary fall in the arterial pressure distally to between 50 and 70 mm. Hg, but recovery to between 90 and 120 mm. Hg occurred routinely within 2 to 5 minutes. This pressure was maintained for the remainder of the occlusion period (30 to 90 minutes). The arterial pressures proximal to the clamp were elevated 10 to 30 mm. Hg (Fig. 2) above the preocclusion level but appeared to have no adverse effect on left ventricular activity. Plasma hemoglobin levels were generally elevated to

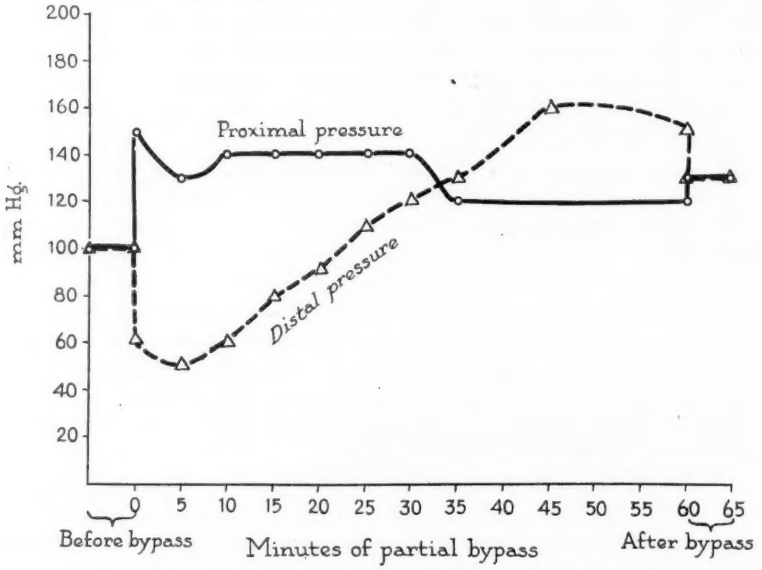

Fig. 2.—Typical blood pressure curve in a partial bypass experiment.

a mean value of 142 mg. per cent at the conclusion of the experiments. No correlation between the extent of hemolysis and the duration of the bypass was evident from the data. Platelet counts were not done routinely but, in the animals in which they were carried out postoperatively, they were found to be within normal range. Gross examination and histologic sections of the kidneys and other viscera of dogs, sacrificed from 10 to 64 days postoperatively, were normal, with the exception of the site of occlusion of the aorta. In 2 dogs, narrowing and infiltration with fibrous tissue were seen and, in a third, actual rupture of the intima with a dissecting aneurysm was present. Following a change in the technique of occlusion, this finding was not seen again.

Seven dogs were subjected to total aortic bypass. Two of these died in the early postoperative period. The 5 surviving animals showed no neurologic or other visceral damage. The general pattern of blood pressure levels was

similar to those of partial bypass, but the proximal pressures were constantly higher than the distal one by 25 to 50 mm. (Fig. 3). There was no evidence of left ventricular dilatation or failure during the 30 to 90 minutes of aortic occlusion nor upon the release of the occluding clamps at the completion of the bypass.

The successful use of this bypass system with the modified Dale-Schuster pump in the experimental animal to maintain distal arterial circulation, and to prevent excessive proximal arterial pressure levels with possible consequent left ventricle damage, led to its clinical application.

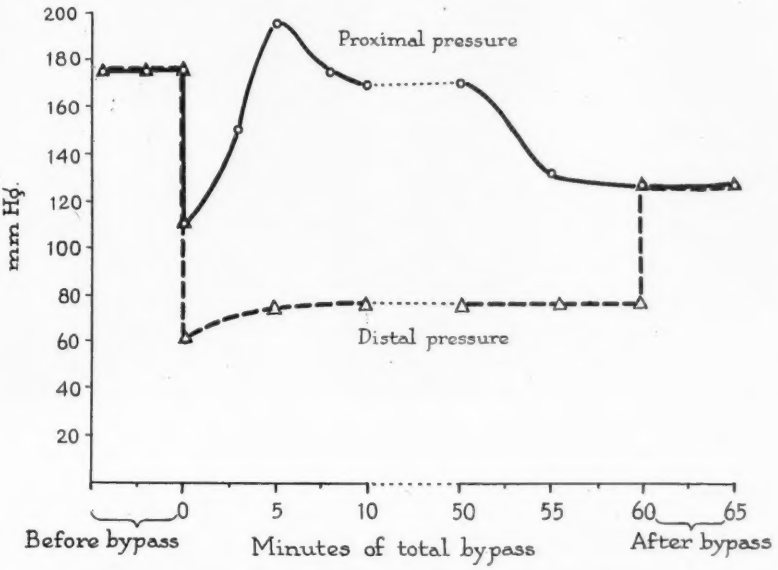

Fig. 3.—Typical blood pressure curve in a total bypass experiment.

CLINICAL APPLICATION

A 65-year-old man, with vague complaints caused by an aneurysm of a descending thoracic aorta, was admitted to Veterans Research Hospital in January, 1958, and after a diagnostic investigation he was submitted to operation on Feb. 11, 1958. Under general endotracheal anesthesia, the chest was opened through a left posterior lateral incision, a large aneurysm of the descending thoracic aorta (Fig. 4) was resected and continuity re-established with an Ivalon-nylon aortic prosthesis.[13] The distal circulation was maintained by the extracorporeal pump bypass from the left atrium to the left femoral artery with the pump just described. During the 56 minutes of arterial occlusion and bypass, the distal arterial pressure was maintained between 50 and 60 mm. Hg and the blood flow through the pump averaged 1,100 c.c. per minute. There was no evidence of cardiac dilatation or failure

during the bypass and 260 c.c. of urine was collected during the procedure. Postoperatively, there was no evidence of neurologic damage and the renal function continued to be normal. The patient was discharged in good condition in March, 1958.

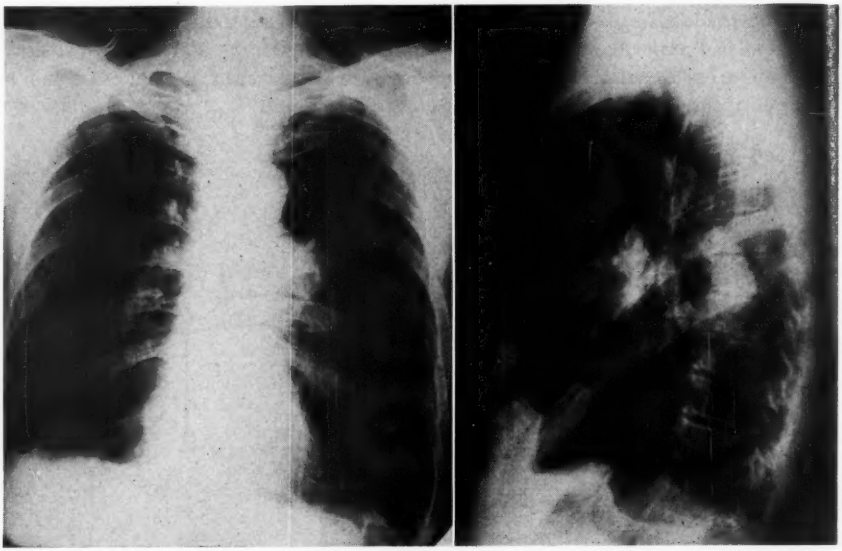

Fig. 4.—Preoperative chest x-rays of the thoracic aneurysm which was resected with the aid of the described extracorporeal bypass pump.

DISCUSSION

From the experimental data obtained, temporary partial or total bypass of the aorta by means of an extracorporeal shunt from the left atrium to a distal systemic artery with the modified Dale-Schuster pump is a satisfactory method of maintaining the distal circulation. Moreover, proximal hypertension did not develop to any severe degree and no detrimental effects on the left ventricle were noted. The amount of circulation provided distally (flow rates varied with the size of animal) were sufficient to prevent neurologic, renal, or other tissue damage. The method appears to be ideal for bypassing the descending thoracic aorta. The use of this method in treatment of aortic arch lesions is not completely solved. Certainly sufficient circulation around the lesion may be supplied, as demonstrated by the total bypass group, but the technical problems of supplying adequate and continuous circulation to the brain remain.

Mention may be made of intimal damage and dissecting aneurysm resulting from clamping the aorta. These lesions occurred when the aorta was occluded with an umbilical tape and a rubber-tipped glass tube. After changing to a Potts' clamp, no further intimal damage was noted. This result is

at variance with the finding of Henson and Rob[7] who found the opposite in a study of the effects of different arterial clamps on the walls of the right gastroepiploic artery in man. However, the essential point is that care and gentleness are necessary in clamping a vessel, irrespective of the type of clamp utilized.

SUMMARY

A modified Dale-Schuster pump is described, and its use as an extracorporeal pump in the partial and total bypass of the aorta is reported. Satisfactory distal circulation was maintained from the left atrium to a distal systemic artery with the aorta occluded either proximal or distal to the aortic arch. Adverse cardiac manifestations (dilatation or failure) were not noted. The usefulness of pump and bypass system is stressed as an aid to surgery of the thoracic aorta.

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EXPERIENCE WITH THE BECK FINGER-DILATOR IN MITRAL VALVULOTOMY

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SINCE Bailey, in June, 1948, and shortly thereafter Brock and Harken, initiated successfully the surgical treatment of mitral stenosis, utilizing commissurotomes, or performing the "finger fracture valvuloplasty," many surgeons throughout the world have devised a large variety of knives and valvular dilators for the purpose of opening the stenotic mitral valve. This is partially indicative of the different personal preferences of each surgeon, but it also points out the lack of an ideal instrument with which to perform a satisfactory commissurotomy in every case of mitral stenosis.

Ideally, every intracardiac surgical procedure should be done under direct vision. The mitral valve has already been approached in this way in different centers, and open heart correction of its lesions has been performed.[1] But the safety margin of extracorporeal circulation up to the present time, as compared with that of the "closed" technique, is too narrow to be used on patients with pure or predominant mitral stenosis. Consequently, in the centers just mentioned, the open heart technique has been used to correct predominant mitral insufficiency or mitral stenosis concomitant with other congenital or acquired lesions, but not to treat cases of pure mitral stenosis.

Even with a sufficiently safe technique of cardiac bypass, there remains the problem of those patients on whom the valve has been too damaged by the rheumatic process to permit its surgical correction, unless a complete valve replacement with a graft or some kind of prosthesis is accomplished. This, no doubt, will be feasible in the future, but it is also certain that there will continue to be operations for pure or predominant mitral stenosis by the "closed" technique for a time that certainly will not be short.

In 1953, after having tried different commissurotomes, devised by himself or by others, and not finding one completely satisfactory, Dr. Claude S. Beck thought of the device and the maneuver which are the subjects of this paper.

It happened while operating on a patient in whom the stenotic mitral valve had been only partially opened with the finger alone. The orifice, from very small, had been enlarged enough to permit the passage of the index finger up to the first interphalangeal joint, but it would not enlarge any more. At that moment it measured approximately 2 cm. in diameter. The idea of enlarging the circumference of the dilating finger came to Dr. Beck's

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mind. For this purpose he wrapped a length of wet cotton tape around the distal phalanx of his finger, and covered this "dilator" with a second glove; re-introducing the finger, so armed, into the auricle, he passed it forcibly through the mitral orifice. Removing the finger from the auricle, Dr. Beck had the second glove and the cotton tape taken off, and then proceeded to explore the valve once more to observe the results. The valvular orifice was completely opened, out to the valvular annulus at both commissures, and no regurgitation had been produced (Figs. 1 and 2).

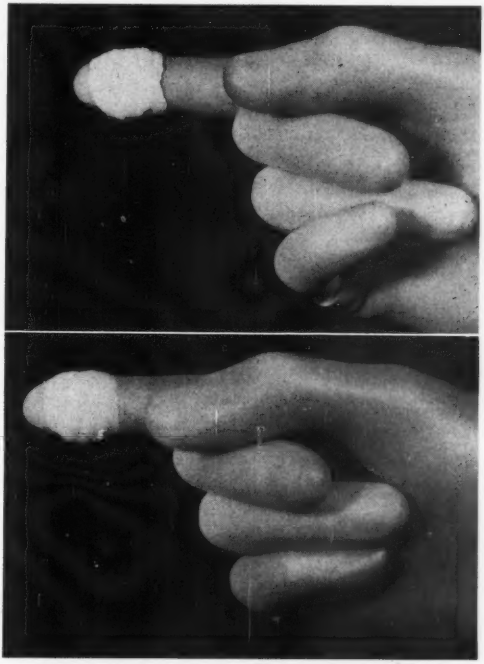

Fig. 1.

Fig. 2.

Fig. 1.—Cotton tape wrapped around the distal phalanx of the dilating finger to form the dilator.

Fig. 2.—A second glove is used to cover the dilator.

Since then Dr. Beck has employed the technique described in most of his cases of mitral stenosis and, up to December, 1954, he had operated upon about 200 patients with this procedure.[2]

At the Surgical Service of the Instituto Nacional de Cardiología de México, this maneuver has been used since April, 1956. Up to the end of April, 1958, 78 patients with mitral stenosis were operated upon by this technique.

In some of these cases, operative tracings were taken of the left auricular pressure, or of both the left auricular and ventricular pressures simultaneously, before and after performing the valvulotomy, with the purpose of having objective evidence of the effectiveness of the maneuver. In these tracings, a substantial reduction of the left auricular pressure, and of the atrioventricular diastolic pressure gradient, can be appreciated (Figs. 3 and 4).

In almost every case in which the procedure has been used, the enlargement of the orifice has extended to the valvular annulus, or very near it at both commissures. This means that the size of the opening obtained has been larger than the size of the dilator. It is easy to understand the mechanism by which this happens: the dilating force, applied eccentrically in all directions, concentrates from the points of greater resistance to those in which

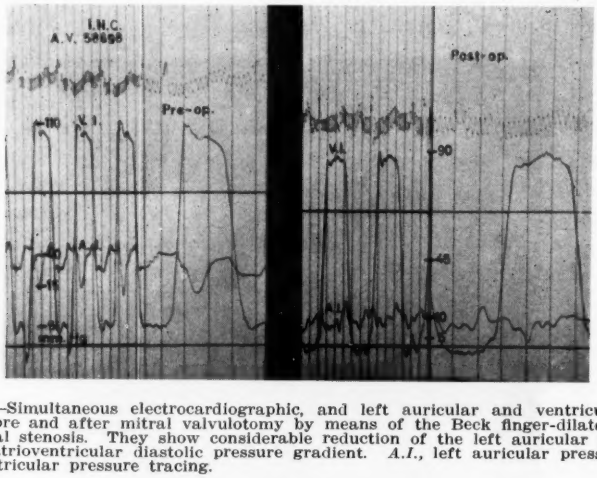

Fig. 3.—Simultaneous electrocardiographic, and left auricular and ventricular pressure tracings, before and after mitral valvulotomy by means of the Beck finger-dilator, in a case of pure mitral stenosis. They show considerable reduction of the left auricular pressure and also of the atrioventricular diastolic pressure gradient. *A.I.*, left auricular pressure tracing; *V.I.*, left ventricular pressure tracing.

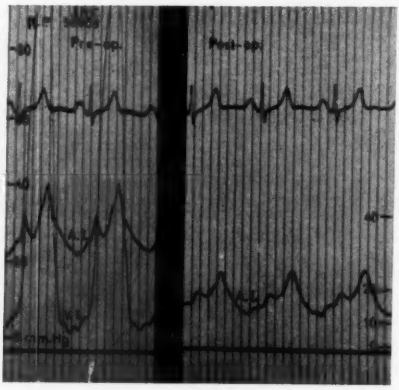

Fig. 4.—The same tracings as Fig. 3 in a patient with predominant mitral stenosis and mitral insufficiency. A left ventricular pressure tracing was not obtained after performing the valvulotomy because the catheter became plugged.

the resistance is lesser, in the moment in which the latter start to give in, and is multiplied at these points until the resistance is overcome. In the case of the mitral valve the points of least resistance are the fused commissures.

Although the latter statement may be a subject for theoretical discussion, and it might be argued that it is possible that the valve may give in at a point other than the commissures, or become detached from its annulus, the fact i

that this has happened neither in Dr. Beck's patients, nor in those operated upon at the Instituto de Cardiología. It is, of course, necessary to take some precautions in order to avoid the occurrence of such accidents. For instance, only a dilator of a reasonable size should be used and, in the event of finding great resistance to its passage through the orifice, a few turns of tape should be taken off in order to make a smaller one. Progressively larger dilators may be used in case it is found that the opening has not been sufficiently enlarged at the first attempt.

In only 3 of the 78 patients operated upon at the Instituto de Cardiología was a small regurgitation (that was not present before the valvulotomy) observed by the surgeon after using the technique described, and none was significant. In only one case of predominant mitral stenosis with mitral insufficiency, was the already present regurgitation slightly increased. In all 4 cases this happened at the commissures or along the valvular orifice, just as happens sometimes when the valve is opened with the finger alone or with a commissurotome correctly placed at the commissures. That is to say, that the slight regurgitation produced was due to factors such as poor valvular mobility or retraction of the edges of the cusps that impair their correct coaptation. In no case was it produced by rupture through the cusps—as may happen when any cutting instrument is improperly used—or by separation of these at their base.

The technique has some limitations; one of them is represented by the small size of the neck of the auricular appendage that makes the introduction of the dilator in the auricle difficult. This difficulty is actually limited to those cases of marked atrophy of the appendage at its base, and specially those in which there is no visible auricular wall on which to anchor the purse-string suture. When a small auricular appendage is found, and enough auricular wall is available, the purse-string may be extended to the auricle proper, and the same may be done with the incision through which the finger is to be introduced, overcoming the difficulty in this way.

Another limitation is produced by the very severe fibrosis of the valve. In some cases the healing of the rheumatic process makes the valve tissue become leatherlike, and it resists a reasonable pressure exerted on it with the dilator. It is then necessary to start the opening of the valve by means of the instrumental cutting of the commissures, and then to complete its aperture with the finger alone or aided with the dilator. This situation was encountered in 4 out of the 78 cases operated on at the Instituto de Cardiología.

Concerning the latter, it must be said that in Dr. Beck's experience, as well as in that of the surgical group of the Instituto de Cardiología, the use of commissurotomes has become exceptional, and the great majority of valves that were resistant to finger dilatation alone have been opened by use of the procedure described.

During the period 1953 to 1955 inclusive, 359 mitral valvulotomies were performed at the Instituto de Cardiología de México; 292 of these were performed with the finger alone (81.4 per cent), and 67 were done by using some kind of commissurotome (18.6 per cent). From 1956 to April, 1958,

there were 379 mitral valvulotomies of which 280 were done digitally (74 per cent); in 78 cases the Beck finger-dilator was used (20.5 per cent), and in only 25 (6.5 per cent) was it necessary to use some kind of commissurotome.

From what has been written, it may be ascertained that our experience is in accordance with that of Dr. Beck, who has stated: "It is my opinion that this method of opening the mitral valve has almost eliminated the creation of mitral valve regurgitation produced as a complication of valvulotomy. The simplicity of this method, and the almost complete lack of danger of producing regurgitation, enable me to recommend it as the preferable method for mitral valvulotomy. After I began to use this method I found it was not necessary to cut the valve."[2]

There exist two other limitations that are not peculiar to this technique alone, but to every "closed" technique employed to perform a mitral valvulotomy; they are (1) the thrombosis of the auricle, and (2) the calcification of the mitral valve. They represent, at the present time, practically the only causes of death as direct consequence of the operation itself, due to the possibility of embolism to vital organs. Rather than limitations, they should be considered risks that will have to be taken until it is possible to proceed, under direct vision, to the evacuation of the thrombi or the particles of calcium, or even to the total replacement of the valve when it is found too deteriorated to permit its surgical repair.

SUMMARY AND CONCLUSIONS

1. The experience obtained at the Instituto Nacional de Cardiología de México with the use of the Beck finger-dilator in mitral valvulotomy is herein presented.

2. The procedure consists of enlarging the circumference of the dilating finger by means of cotton tape wrapped around the distal phalanx of the finger, and forcibly passing it through the mitral orifice.

3. Of the last 379 mitral valvulotomies, 78 patients who represent 20.5 per cent, have been operated upon under this procedure.

4. The use of commissurotomes was reduced from 18.6 per cent, in which some cutting instrument was used in a previous similar group of 359 patients, to 6.5 per cent in the 379 patients operated upon since the use of the Beck finger-dilator was started.

5. The production of mitral regurgitation, that was not present before the valvulotomy, was minimal, both regarding the number of cases in which it was produced—only 3—and also with respect to its magnitude.

6. The advantages and the limitations of the procedure have been presented, as well as the ways in which the latter may be overcome.

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A PLANNED STUDY OF MINIMAL TUBERCULOSIS

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THIS report presents data from a planned study of minimal tuberculosis regarded as clinically active, treated by bed rest, chemotherapy, and resections of residual lesions; together with detailed pathologic studies of each surgical specimen, and follow-up information.

The approach to the problem of minimal tuberculosis in this way was influenced by several factors.

1. In the fall of 1951 studies at Biggs Memorial Hospital[1] of minimal tuberculosis had shown that, in the pre-drug era, 1 in 5 patients active at diagnosis either had had a relapse of disease or were dead within 10 years.

2. At the start of this study, there had not been time for evaluation of the long-term use of drugs in treating this stage of the disease.

3. The Biggs staff had participated in the original studies of the antituberculous drugs. While their value had been demonstrated, it was recognized that lesions did not resolve completely.

4. The surgical service of this and other hospitals[2] had already shown that operations on lungs involved with tuberculosis were feasible and not unduly hazardous.

5. One of the authors, Edgar M. Medlar, had shown in autopsy studies at Bellevue Hospital[3] that in 96 minimal cases the disease was unilateral in 82 per cent and that in 93 per cent of the reinfection type of disease it was localized in the apical and/or posterior segments. This suggested to us that such lesions should be easily amenable to surgical approach.

6. He called attention to the fact that the group at Sunmount had reported[2] on the excision of 30 localized lesions and had demonstrated the presence of necrotic foci.

7. He had also shown[3] that any minimal lesion of a size which would be visible on the roentgenogram had a necrotic component, which presumably would be the source of an exacerbation if this occurred.

8. Great emphasis had been given to the discovery and treatment of pulmonary tuberculosis in its "minimal" stage, when the disease was considered to be "curable." The programs that had previously been devised toward

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this goal had lacked one essential element, i.e., a documentation of the exact nature of the pathologic process present in minimal cases. One of the purposes of the present study was to document in detail the pathologic features found in the tissues resected during treatment with chemotherapeutic agents. From a study of this nature, it seemed probable that the dynamics of the pathologic process could be determined.

The staff decided to study the concept that minimal tuberculosis be considered a surgical problem on the basis that resection of residual necrotic lesions would prevent relapses of the disease. It was the aim to include all patients classed as minimal active (and which had never been known to have more extensive disease), to treat them with antituberculous drugs in the then currently accepted manner and to excise the residual lesions.

Diagnosis was based on a positive tuberculin and an unstable lesion as seen in serial x-rays. Demonstration of tubercle bacilli was not required. All patients diagnosed as having minimal active tuberculosis were included, the exceptions being a few who declined surgery. Complete roentgenographic studies, including planigrams in all but a few, were carried out. All recognizable foci, including bilateral lesions, were considered indications for proposing surgery. At operation the collapsed lung was carefully palpated and the location of all lesions noted. An effort was then made to excise all areas of disease utilizing such surgical approach as was best suited.

The group studied consisted of 104 patients of whom 15 had bilateral excision. The operations were done between September, 1951, and December, 1955, inclusive. There were 43 males and 61 females, with 24 under 20 years of age, 68 between 20 and 39 years of age, and 12, 40 years of age or over (Table I).

TABLE I. RESECTION FOR MINIMAL TUBERCULOSIS
PATIENTS BY AGE AND SEX

SEX	AGE (YEARS)					TOTALS
	10-19	20-29	30-39	40-49	50-59	
M	10	14	11	5	3	43
F	14	25	18	3	1	61
Totals	24	39	29	8	4	104
Bilateral Patients (included in above)						
M	2	–	1	–	–	3
F	1	4	6	1	–	12

The type of chemotherapy varied as the usage of drugs changed, and new drugs became available. Sixty patients received streptomycin, and para-aminosalicylic acid (PAS), while 43 received isoniazid in some combination. One patient received no drug therapy. The drugs were used until it was felt that maximum clearing had occurred. The preoperative duration of such therapy was 4 months or less in 36; 5 to 8 months in 56; and over 8 months in 11 (Table II). Concentrate negative sputum was the rule at operation but was not required.

TABLE II. RESECTION FOR MINIMAL TUBERCULOSIS
PREOPERATIVE CHEMOTHERAPY—104 PATIENTS

DRUGS	PATIENTS	MONTHS OF CHEMOTHERAPY (PREOP.)		
		0-4	5-8	8 OR OVER
SM* + PAS†	60	21	30	9
SM + INH‡	22	10	12	–
PAS + INH	14	4	9	1
SM + INH + PAS	6	–	5	1
INH + PZA§	1	1	–	–
Totals	103	36	56	11
No drug given	1			

*Streptomycin; †para-aminosalicylic acid; ‡isonicotinic acid hydrazide; §pyrazinamide.

Postoperatively, drugs were at first given to cover the recovery period only, but when excised specimens showed areas of new disease to have occurred during drug therapy, the drugs were arbitrarily given postoperatively for 4 months. During this period, a graduated program of increasing activity was carried out with discharge at the end of 4 months. Twenty-eight patients had received postoperative drug therapy for 2 months or less, 16 for 3 months, 56 for 4 months, and 3 more than 4 months following surgery (Table III).

TABLE III. RESECTION FOR MINIMAL TUBERCULOSIS
POSTOPERATIVE CHEMOTHERAPY—104 PATIENTS

DRUGS	PATIENTS	MONTHS OF CHEMOTHERAPY (POSTOP.)			
		0-2	3	4	OVER 4
SM + PAS	60	24	9	26	1
SM + INH	19	1	6	12	–
PAS + INH	19	1	1	15	2
SM + PAS + INH	4	2	–	2	–
PZA + INH	1	–	–	1	–
Totals	103	28	16	56	3
No drug given	1				

The bacteriologic studies showed 25 with positive smears of concentrated sputum, 50 with positive cultures of sputum or gastric contents, and 29 negative on initial study. Prior to operation, 18 of the 25 had converted on smears of concentrates while 48 of those positive on culture had converted to negative (Table IV).

TABLE IV. RESECTION FOR MINIMAL TUBERCULOSIS
SPUTUM STATUS

SPUTUM BEFORE CHEMOTHERAPY	SPUTUM BEFORE OPERATION			TOTALS
	CONC. +	CULT. +	CULT. –	
Conc. +	7	2	16	25
Culture +	2	–	48	50
Culture –	–	–	29	29
Totals	9	2	93	104

The major complications of surgery included 5 hemothoraces, one of which was massive, 3 bronchial fistulas, and 3 others (Table V). The incidence of complications decreased as experience was gained; all responded to therapy.

TABLE V. RESECTION FOR MINIMAL TUBERCULOSIS
MAJOR POSTOPERATIVE COMPLICATIONS
119 OPERATIONS—11 COMPLICATIONS—9 PATIENTS

Massive hemothorax	1
Limited hemothorax	4*
Empyema	1*
Bronchopneumonia	1*
Excessive early air leak	1
Infected segmental space—bronchial fistula	3
Total	11

Four of these 11 patients also had minor complications.
*One patient had three complications.

Transient pneumothoraces and undue retention of bronchial secretions were regarded as minor complications (Table VI). Here again, as surgical techniques and aftercare improved, the complications became less frequent.

There were no operative deaths.

TABLE VI. RESECTION FOR MINIMAL TUBERCULOSIS
MINOR POSTOPERATIVE COMPLICATIONS
119 OPERATIONS—15 COMPLICATIONS

Pneumothorax	10*
Rentention of secretions in bronchus	4
Esophagitis due to antibiotic idiosyncrasy	1

*Four patients also had serious complications.

The time which elapsed between the diagnosis of active disease and initiation of chemotherapy was relatively short. It was less than one month in 23 and between 1 and 6 months in 43. A longer interval was noted in 38 (Table VII).

TABLE VII. INITIATION OF CHEMOTHERAPY

TIME AFTER DIAGNOSIS	PATIENTS
Less than 1 month	23
1 to 6 months	43
Over 6 months	38*
Total	104

*Among these there were 9 patients with prior hospitalization and later relapse.

The concept of the therapeutic approach, the program of management, and the surgical considerations have been presented. The following section of the report is devoted to the pathologist's studies.

PATHOLOGIC STUDY

Canetti[4] has stated that: "Contrary to what is usually believed, tuberculosis is not a general disease, at least in the usual sense of the word." He further believes that the pre-eminence of local factors is clearly illustrated by several clinical facts, among them the fact "that many tuberculous patients are apparently cured by simple surgical excision of local areas."

One of the authors has independently pointed out[3, 5] that minimal pulmonary tuberculosis usually is not a part of a generalized infection but

that it is a localized disease which occurs predominantly in the superior and posterior portions of pulmonary lobes. These locations are most often in upper lobes, unilateral, and more restricted in reinfection than in primary disease. While that study demonstrated a more complete picture of minimal disease, it lacked clinical and roentgenographic data for correlation with the pathologic findings.

In the present study, all cases were considered initially clinically active and at operation all palpable disease was excised. Not infrequently more disease was found at operation than was suspected from chest roentgenograms and, on occasion, lesions were found in areas not suspected preoperatively. In the 104 cases, a total of 119 lungs were explored and the disease excised; 89 unilateral and 15 bilateral. Because of extensive developmental bronchiectasis, a right lower lobe with some tuberculosis was removed in one case. In the remaining 118 lungs only segments or subsegments were excised. The location of the disease excised is shown in Table VIII. In only 4 lungs was there an absence of disease in the apicoposterior portion of an upper lobe or in the superior segment of a lower lobe; one of these was in the right middle lobe, one in the basal segment of a lower lobe, and 2 in the anterior segment of an upper lobe. This distribution of disease in the 119 explored lungs tallies closely with the distribution found at necropsy.[2] These findings indicate that as long as the disease remains minimal in extent roentgenologically, it is *essentially* a localized process. However, in a *few* cases, quite distant and unrecognized endobronchial disseminations may be present.

TABLE VIII. RESECTION FOR MINIMAL TUBERCULOSIS
DISTRIBUTION OF EXCISED DISEASE

SEGMENTS INVOLVED	RIGHT	LEFT	TOTALS
Apicoposterior only	39	40	79
Apicoposterior + superior	7	5	12
Apicoposterior + other	9	10	19
Superior only	1	2	3
Superior + other	–	1	1
Other not listed above	2	2	4
	58	60	118

Plus 1 lower lobe for a total of 119 resections.

The pathologic observations in the resected specimens were recorded, case by case, without reference to either the clinical record or to the type and duration of chemotherapy.

Bacteriologic examinations of the resected material were a minor feature in this study. In many instances such bacteriologic examination was deliberately kept at a minimum to allow complete morphologic studies.

Technique.—

All specimens were promptly fixed in toto, with a minimum of handling, in a 4 per cent solution of formaldehyde. Incision of the fresh specimen was restricted to the few cases in which bacteriologic culture was done. After several days' fixation, the specimens were sectioned in 4 mm. slices for the

macroscopic study. From all specimens the majority of the tissue slices, and in many instances all, were processed for microscopic study. Tissue blocks were decalcified as need arose. Whenever possible, tissue blocks up to 4.5 cm. square were taken.

Several thousand random tissue sections thus became available for microscopic study and a comprehensive idea of relationships and of cellular detail was obtained.

Significant Pathologic Findings—104 Cases, 119 Lungs.—

In the prior necropsy study,[3] it was noted that with few exceptions minimal tuberculosis represented both primary and reinfection disease with primary infection predominant in the younger ages and reinfection predominant in persons beyond the fourth decade. Both primary and reinfection "minimal" tuberculosis were encountered in the group presented here.

In the study of the pathology, one lone case showed parenchymal scarring only. All other specimens showed multiple necrotic lesions and scarring but with considerable variations both in size and number of necrotic foci and amount of scar. There were considerable differences in the ages of the various types of lesions not only from case to case but within single specimens. Under these circumstances the most significant morphologic features are tabulated so as to indicate the frequency with which they were found according to cases rather than specimens as follows:

I. Macroscopic Features—104 Cases			
A. Multiple necrotic (caseous) lesions and parenchymal scarring			103
1. Necrotic (caseous) component dominant		83	
2. Non-necrotic component dominant		20	
a. "Tubercles" predominant	4		
b. Scarring predominant	16		
B. Evidence of cavity formation			48
1. Open		14	
2. "Filled in"		30	
3. Largely scar		4	
C. Pleural adhesions present			78
D. Calcific lesions present			37
E. Developmental bronchiectasis			7
F. Parenchymal scarring only			1
II. Microscopic Findings—104 Cases			
A. Parenchymal lesions			
1. Neutrophilic infiltration in necrotic lesions		60	
2. "Epithelioid" tubercles		53	
3. Recent pneumonic foci		10	
4. Parenchymal scarring only		1	
B. Bronchial lesions			
1. Bronchial communication with necrotic lesions		49	
2. Necrotic endobronchial tuberculosis		28	
3. Squamous metaplasia of bronchial epithelium		18	
4. Stenosis (small branches)		2	
5. Developmental bronchiectasis		7	

These data clearly indicate that a pathologic process of considerable complexity can be expected in any sizable group having clinically active minimal pulmonary tuberculosis. With such a complex pathologic process it would seem logical to regard the element of time as the most important single factor. The clinical records reveal that the lesions were removed anywhere from 4 months up to 10 years after the discovery of the disease. The pathologic picture reveals that in the majority of cases the time element is considerably longer than indicated in the clinical record. The time factor is so elusive that it becomes useless unless one dogmatically assumes that certain characteristics denote a certain age. Such personal opinion is not tenable on the basis of fact. For example, in one specimen the dominant feature may be "epithelioid" tubercles that vary in structure with the presence of only a few small well-encapsulated necrotic foci; in another, the dominant feature may be necrotic lesions of different sizes and appearances with minor parenchymal scars; in another, parenchymal scars may be dominant with only a few small innocuous appearing necrotic foci; and, in still another, there may be a fairly even mixture of all of these features. With such a variable and complex pathologic picture, it seems most difficult, if not impossible, to use a single or a combination of several morphologic features as a yardstick to determine either the duration of the time factor or the effect of any chemotherapeutic regimen.

This situation is further illustrated by the use of a single morphologic feature. It is well recognized that the endobronchial dissemination of tuberculosis requires the liquefaction and the sloughing of necrotic (caseous) lesions. In our opinion, the neutrophil through its proteolytic enzyme plays a decisive role in this process. The presence of neutrophils in necrotic lesions was noted in over one half of the cases. On the hypothesis that chemotherapy might stop the process of liquefaction, the cases were tabulated to determine whether there was a correlation between the length of time chemotherapy had been given and the amount of neutrophilic infiltration of the necrotic tissue. To show the variations found, two pairs of cases will be cited. In one pair, chemotherapy was begun promptly after the disease was discovered; in one, resection was done after 4 months of therapy and no neutrophilic infiltration of necrotic tissue was observed; in the other, resection was done after 8 months of chemotherapy and marked neutrophilic infiltration was present in several necrotic foci. In the other pair, comparable as to relationship of initiation and duration of chemotherapy, one showed no neutrophilic infiltration of necrotic tissue, while in the other the majority of the necrotic foci were considerably infiltrated with neutrophils. This difference between cases could be attributed to a difference in the manner in which an *individual* reacts to the infection. However, on several occasions, it was observed that in two closely associated necrotic lesions of similar size and macroscopic appearance one would show no evidence of neutrophilic infiltration and the other would be considerably infiltrated. The behavior of the necrotic focus, therefore, is most unpredictable and no convincing evidence has been obtained to indicate that this behavior has been radically altered by chemotherapy.

The illustrations which accompany this paper have been chosen to show several important pathologic features which the authors consider to be most relevant to the dynamics of the residual disease process after varying combinations and duration of chemotherapy. Low-power magnifications only have been used; to the clinician and the surgeon the features of relationships rather than of cellular details are of greatest significance.

Some general impressions which cannot be substantiated by morphologic data were gained from this study. The amount of clearing of roentgenographic shadows varied considerably from case to case. In some with considerable clearing, the tissue sections showed little residual scarring. It is assumed in these cases that the major portion of the pneumonic exudate in the recent endobronchial disseminations had resolved without leaving any permanent damage to the involved area. In those cases which had an insignificant amount of roentgenographic clearing, some showed a dominance of parenchymal scarring, while others showed a dominance of necrotic foci with only a small amount of scarring. From this, it would appear that extensive parenchymal scars cast roentgenographic shadows which cannot be clearly differentiated from those of necrotic lesions. In this study it would have been a correct assumption that the residual shadows were due to necrotic foci.

It was unusual to find "epithelioid" tubercles in specimens removed after more than 4 months of chemotherapy, unless there was evidence of recent liquefaction and sloughing. The "epithelioid" feature of the process seems to disappear fairly promptly under chemotherapy. From the abundant evidence of fibrosing of these tubercles, one may assume that the parenchymal scarring, so frequently encountered, represents the healed stage of "epithelioid" tubercles.

The finding of evidence of cavity formation in almost half of the cases was not anticipated. No evidence of cavity was noted in the usual postero-anterior chest roentgenograms. Planigraphy revealed suggestive evidence of cavity in six. The specimens from these 6 showed cavity formation in only one. None of the open cavities had a lumen over 5 mm. and it is not to be expected that such small cavities could be identified even by planigraphy.

Bronchial communication with a necrotic focus was found, microscopically, in 49 cases. Usually this situation was observed in a single necrotic lesion in a specimen, but in one instance such a situation was found in 4 necrotic lesions. When it is considered that several thousand sections containing numerous necrotic foci were examined, it is evident that, in tissue sections prepared in a routine manner, the finding of a bronchus opening into a necrotic focus would be infrequent. This suggests either that this phenomenon is unusual or that the opening in the necrotic lesion is difficult to locate. To investigate the latter possibility, complete serial sections were made of 4 necrotic lesions, each about 1 cm. in diameter. In each instance there was a direct bronchial opening to the zone of necrotic tissue. In each set of serial sections the bronchial connection did not extend through more than 6 consecutive sections 15 μ in thickness. Although only a few lesions were thus studied, it would seem reasonable to assume that bronchi are intimately associated with most necrotic lesions. In our opinion, this is the danger point in unsloughed necrotic lesions; it is of microscopic proportions and is difficult to locate.

Fig. 1.—White woman, age 34. Known calcified lesion at age 30. New active lesion, age 34. Sputum culture positive. INH and PAS 5 months, minimal clearing. Resection, segmental plus calcified focus. Old calcified lesion, lower lobe, interpreted as obsolete focus of a primary complex.

Illustrated lesion, regarded as "exogenous reinfection," shows predominantly necrotic disease such as was present in 83 of the 104 cases. Smear from large lesion was 2 plus for acid-fast bacilli; culture, negative. Lesion showed some disintegration of lung tissue and neutrophilic infiltration and, in part, intact dead lung framework (elastic tissue). Other features were scattered necrotic lesions of various sizes, rare fibrosing "tubercles," and a few scars. (×5; reduced ⅓.)

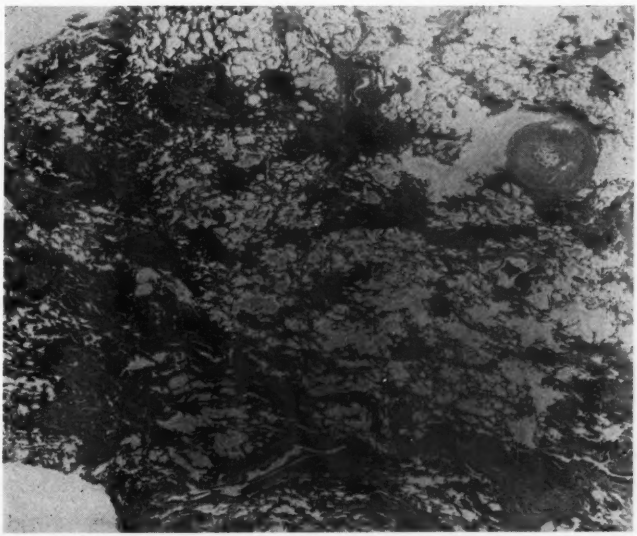

Fig. 2.—White woman, age 18. Diagnosis after hemoptysis. Gastric cultures and tuberculin positive. SM and PAS 6 months. Moderate clearing. Resection, segmental.

Illustration shows parenchymal scars, the dominant feature in 16 cases. Interpreted as end stage in healing of "tubercles." A small, open, sloughing cavity was present in another area of the specimen (not shown). Calcified spot within necrotic focus, *upper right*, suggests disease of some duration; parenchymal scarring might have antedated chemotherapy. (×10; reduced ⅓.)

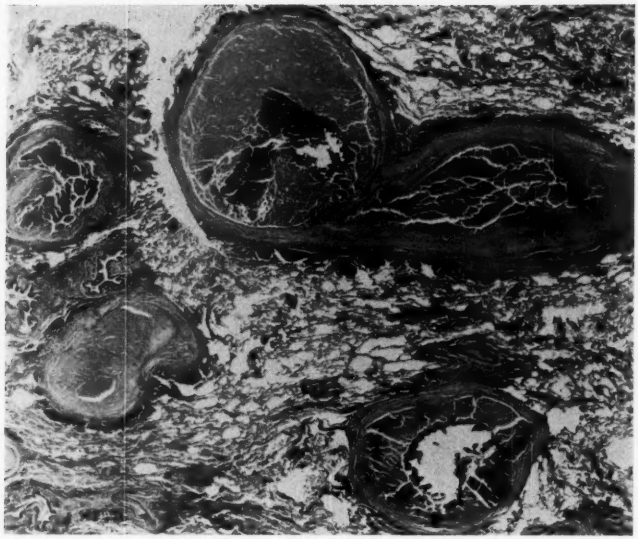

Fig. 3.—White woman, age 24. Diagnosed when 6 months pregnant. Treatment started after delivery. Tuberculin positive, gastric culture positive, converted after first month. SM and PAS 6 months with minor changes in roentgenograms. Resection, segmental, plus two hilar nodes.

Two areas show calcification in well-encapsulated necrosis; two other areas show neutrophilic infiltration in necrotic centers, while one necrotic area shows dead lung framework (elastic tissue). All have fibrotic peripheries. Lymph nodes showed lesions with calcification. Interpreted as primary infection, probably of some duration. Morphologic variations shown were encountered not infrequently. (×10; reduced ⅓.)

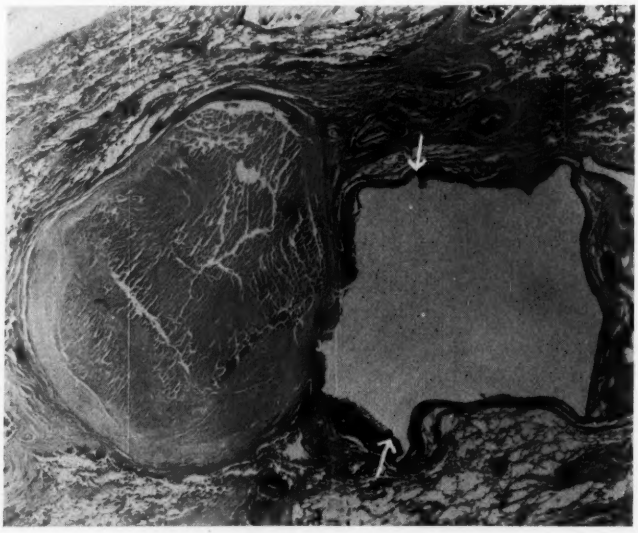

Fig. 4.—White woman, age 18. Diagnosed after negative survey films for 3 years. Tuberculin positive, gastric culture negative. SM and INH 6 months, moderate clearing. Segmentectomy.

Illustration shows bronchial connection with necrotic lesion. Bronchial structure to left of arrows in seat of necrotic endobronchial tuberculosis; to the right, bronchus is normal. Fibrotic periphery of lesion, *left*, well formed—acellular. (×10; reduced ⅓.)

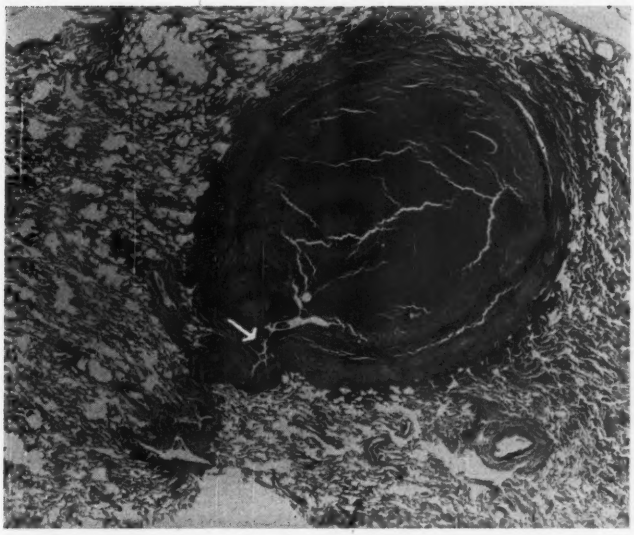

Fig. 5.—White woman, age 36. Known calcific lesion, *left lower* 9 years. Tuberculin positive. Then new lesion, *left upper*. Gastric cultures negative. SM and INH 7 months, considerable clearing. Segmental resection, plus excision calcific area.

Lesion had thick, cellular fibrotic periphery and necrotic center heavily infiltrated with neutrophils. Direct bronchial opening (*arrow*), stratified squamous epithelium on adjacent fibrotic wall. Bacilli present, although hard to find, in liquefying central portion. Calcified area from lower lobe apparently an obsolete primary focus. Upper lobe lesion interpreted as exogenous reinfection. (×10; reduced ⅓.)

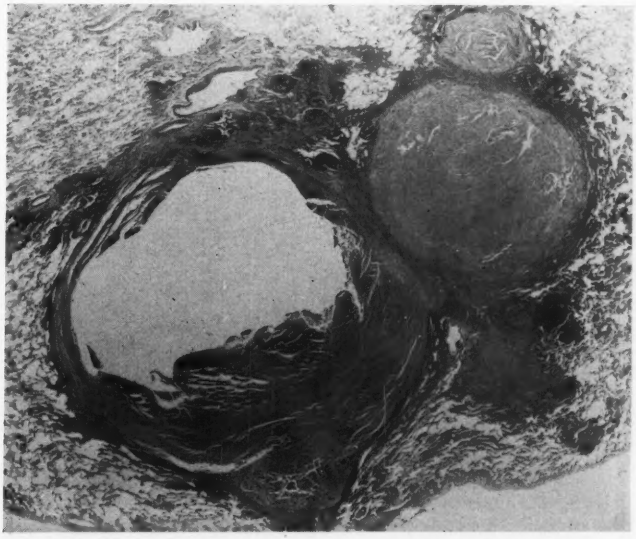

Fig. 6.—Same case as shown in Fig. 5.

Shows small open cavity and several adjacent but separate areas of disease. Two necrotic lesions, *right upper*, have intact lung framework (elastic tissue), fibrotic peripheries more cellular than cavity-bearing lesion; they seem to be younger. Below these is an area with fibrosing tubercles, giant cells numerous. Similar findings in tissue about cavity. Many small colonies of acid-fast bacilli in tissue adjacent to and below cavitary hole. This of interest in view of failure to demonstrate bacilli before surgery. (×10; reduced ⅓.)

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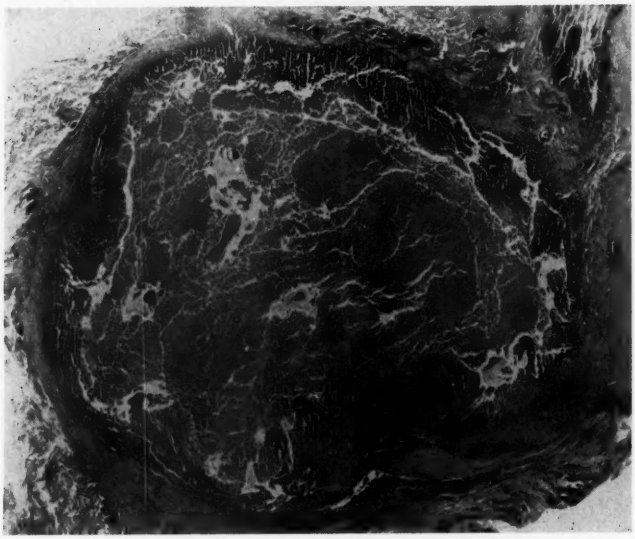

Fig. 7.—White man, age 52. Diagnosis after surgery. Sputum culture positive. SM and INH 4½ months, immediate sputum conversion. Segmentectomy.

Illustrates filled-in cavity. Necrotic contents granular. Darker peripheral zone is layer of granulation tissue with lymphocytes and monocytes but no giant cells. This represents the most common condition in which cavities were found in this study, 30 out of 48. (×10; reduced ⅓.)

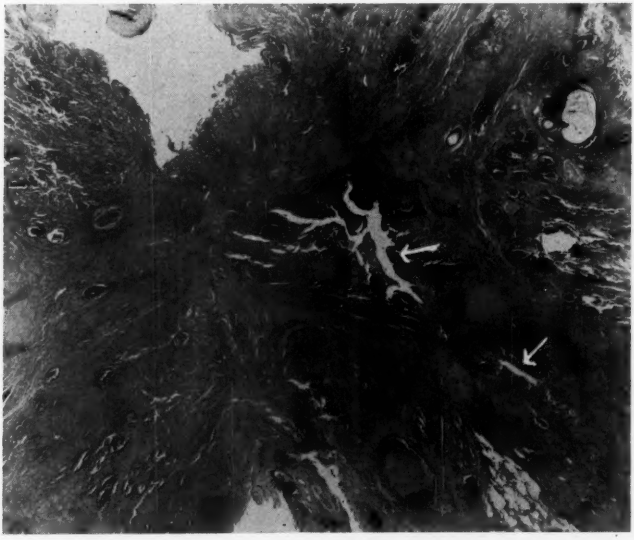

Fig. 8.—White woman, age 44. Diagnosis 1 year after "pleurisy." Sputum positive, concentrate and culture. SM and PAS 9 months (6 ambulatory), then spread. Bed rest and INH added 5 months, slight clearing. Segmentectomy.

Illustration from area of cicatrization suggesting almost complete healing of cavity, but necrotic area in center is unhealed remnant. Arrow to right shows bronchial communication. Epithelium largely squamous, a constant finding where ulcerated surface has healed. The sizable star-like scar is characteristic of cicatrizing cavities. (×10; reduced ⅓.)

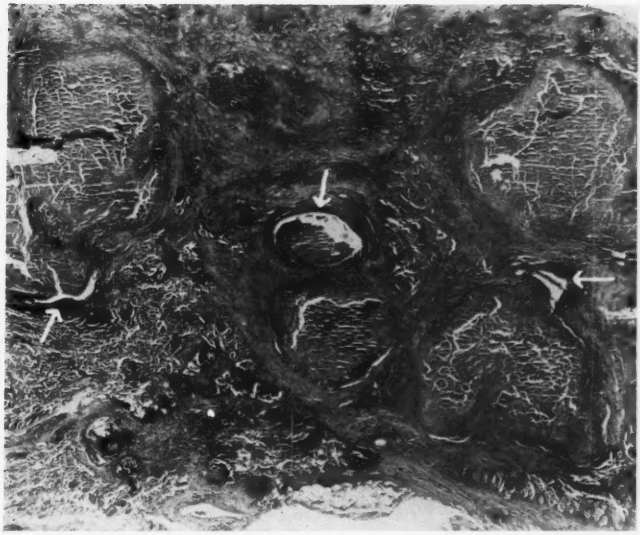

Fig. 9.—Same case as shown in Fig. 8.

Illustration from area of "spread" shows fibrosing tubercles with giant cells, necrotic lesions with considerable neutrophilic infiltration. Arrows to right and left indicate bronchial communications. Central arrow indicates bronchus filled with neutrophilic exudate and necrotic debris; it has extensive necrotic ulceration.

This disease considered not over a few months old. Note is made of (1) spread of disease under chemotherapy, and (2) liquefaction of necrotic lesions after 5 months of triple drug therapy (14 months total drug therapy). (×10; reduced ⅓.)

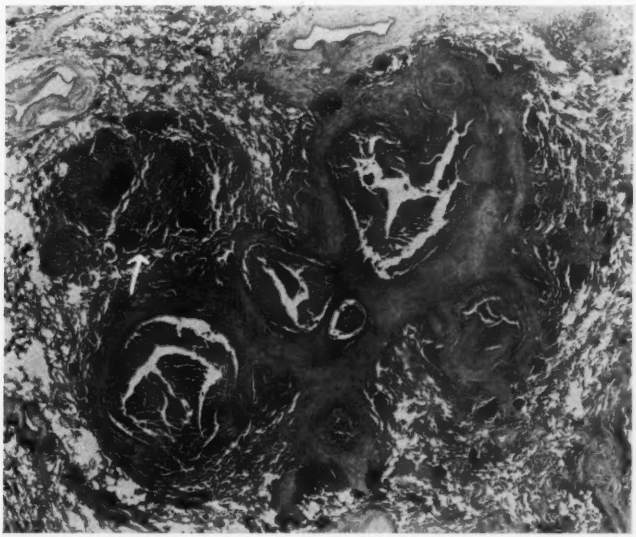

Fig. 10.—White woman, age 27. Diagnosis 5 years before, treated, recovery without drugs. Well until 2 months before readmission, symptomatic, x-ray spread. Sputum positive, concentrate and culture. SM and PAS 8 months. Conversion after 4 months, considerable clearing. Segmentectomy.

Illustration shows recent area of lobular pneumonia, exudate in alveolar spaces, a mixture of neutrophils, monocytes, and lymphocytes. Alveolar walls thickened with leukocytic infiltration. No tubercles, giant cells, foci of necrosis, or peripheral fibrotic zone. This feature noted in 10 of the 104; evidence that small endobronchial spreads can occur during chemotherapy. (×10; reduced ⅓.)

Necrotic endobronchial lesions were found frequently and were always in the smaller bronchial radicles. The ones included in the table were identified by the presence of some bronchial epithelium or small bits of cartilage. Unless some typical feature of a bronchus is noted, these lesions remain unrecognized. Stenosis of smaller bronchial branches was rarely found; in the two instances included in the table, there were necrotic endobronchial lesions in the distended bronchi distal to the stenosis.

Stratified squamous epithelial metaplasia of bronchial epithelium was noted on several occasions. This was not uniformly found at the bronchial entrance to a necrotic lesion nor at the edges of necrotic ulceration of bronchi. This phenomenon apparently occus only in those instances in which the necrotic tissue had been cleanly sloughed and a healthy granulation tissue has been produced adjacent to normal bronchial epithelium. It appears to be a constant feature whenever bronchial epithelium grows out to cover the clean granulating bed of an ulcer intimately associated with a bronchus.

COMMENT

Minimal pulmonary tuberculosis is a clinical term which connotes the roentgenographic extent of the disease. From clinical data, a patient may be considered as active or inactive and in this study only ones with active disease have been included. These cases can be divided into four categories: (a) active on the first chest roentgenogram ever taken; (b) disease of recent origin with previously normal chest roentgenograms; (c) patients who have been followed for variable periods of time and considered inactive until instability of roentgenographic shadows was observed; and (d) an increase of roentgenographic shadows in individuals who had attained an arrest of disease during a previous hospitalization. It is evident that the element of time, which considerably affects the pathologic process, varied greatly from case to case. This, in our opinion, is the situation in clinical tuberculosis as a whole.

It has long been recognized clinically that pulmonary tuberculosis runs a chronic, unpredictable course with periods of progression and regression in large numbers of patients. Likewise the value of any type of management of tuberculous patients cannot be clearly evaluated until several years have elapsed after treatment.

In the past, pathologists generally have gained their knowledge of pulmonary tuberculosis, in large part, at the necropsy table. Their chief concern has been the determination of the condition which led to the demise of the individual. Usually, a general and sketchy macroscopic description of the pulmonary situation is made and only sufficient microscopic study is done to substantiate the macroscopic diagnosis. Usually, little attention is given to a limited amount of tuberculosis of the lungs of an individual who has died from other causes. The dynamics of tuberculous disease has received little attention and commonly there is an inadequate attempt to correlate the clinical and pathologic data. Generally the work load of the pathologist is so great that time and assistance are inadequate to permit a painstaking study of the

details of the dynamics of disease. Everyone has had to be satisfied if a cause of death has been given. These statements are made with no intent of undue criticism.

These two situations were probably of little moment until it was demonstrated that chemotherapeutic agents could, in a large majority of patients, bring the tuberculosis under prompt clinical control. Then the hope was voiced that, with drugs, the disease could be "completely healed." At this point pathologists were asked to determine whether pathologic facts would substantiate a concept of "complete cure." When they referred back to the accumulated knowledge, they found a dearth of solid facts relating to the subtle details of the dynamics of the disease. With renewed interest pathologists and bacteriologists have embarked upon intensive studies, both morphologic and bacteriologic. Certain features which had not been previously documented in full were attributed to the effect of the chemotherapeutic agents without substantial proof of a cause-effect relationship.

The present situation is both unavoidable and unfortunate for it has led to a considerable divergence of opinion among pathologists and bacteriologists. This has led to an even greater confusion relative to the use of drugs and of surgery. The focal point is the necrotic (caseous) lesion, for it constitutes the major portion of the resected disease and is the major harborer of bacilli. At present, most pathologists regard a well-encapsulated necrotic lesion, as found in random tissue sections, as an innocuous affair even if tubercle bacilli are found within the necrotic core. In our experience, lesions of this type are the most unpredictable part of the disease process. A sufficient study of this portion of the pathologic process has been done to satisfy us that necrotic lesions cannot be adequately understood from random tissue sections prepared in the usual routine manner. In our opinion, the delimiting zone of scar tissue that is laid down between the necrotic lesion and the surrounding healthy tissue is Nature's way of protecting the normal tissue and there is scant evidence to indicate that this function fails. Of much greater concern is the bronchial relation to, and the process of, liquefaction of the necrotic lesion. From our experience, we are of the opinion that patulous bronchial communication with the necrotic pulmonary tissue is common, much more so than is generally appreciated. This is the weak spot in the protective mechanism.

The process of liquefaction of the dead tissue is an enigma. Neutrophilic infiltration of the dead tuberculous tissue was one of the more common findings in the pathologic study of the specimens. Usually it was limited to focal areas and, in the examination of different levels of a sizable lesion, the location and size of such areas were variable. In our opinion, liquefaction of the necrotic tissue is induced, in large part at least, by the invasion and the proteolytic action of neutrophils. If a small area of necrotic tissue is liquefied near a bronchial opening then, without demonstrable cavity formation, small dribbles can occur into the bronchus and the stage is set for new endobronchial dissemination. It seems probable that the seriousness of this situation would be dependent upon the numbers of bacilli in the sloughing debris.

Perhaps the most important feature of this pathologic study has been the opportunity to obtain a comprehensive survey of tuberculous disease of limited extent. Although these cases have been considered as "minimal" on clinical grounds, this diagnosis is purely arbitrary if one considers the variations in the volume of disease. Among these specimens there were found the various morphologic features which characterize tuberculous disease as a whole: from cavities which had largely, but not wholly, healed by cicatrization to those with no evidence of healing; from densely calcified or completely hyalinized necrotic lesions to those in which there was an actively forming fibrotic periphery; from early "epithelioid" tubercles without evidence of either necrosis, giant cells, or fibrosis to fibrotic ones in which only a rare giant cell was noted; from small focal areas of lobular pneumonia of such recent origin that there were no earmarks to denote tuberculous infection to abundant giant cells in some specimens and complete absence of these structures in others; and parenchymal scars of various sizes with and without lymphocytic infiltration. In some specimens practically all of the features just mentioned were found. In some specimens it was apparent that the disease must have been of considerably longer duration than suspected clinically and in others the nature of the disease would tally fairly closely with the clinical story. Under these circumstances, it would seem that caution should be used in the interpretation of morphologic features and their relationship with chemotherapy because there may be a limit to the reliability of these features as an index. The question which arises is whether Nature carries on with the reparative process, as in the era before chemotherapy, or whether chemotherapy definitely stimulates and accelerates this natural process. From the considerable variation noted between cases, it seems more logical to credit Nature with the healing or non-healing rather than to transfer such credit to the chemotherapeutic agents. One feature would seem to be undebatable: chemotherapy failed to eradicate either the necrotic tissue or the bacilli which it may harbor. This problem still remains unsolved.

This study was undertaken with two objectives considered of equal magnitude. One was to test the validity of the concept that minimal tuberculosis could be properly treated by a combination of rest and chemotherapy, followed at the appropriate time by resection surgery. The immediate results are quite satisfactory but long-term follow-up will be necessary for full evaluation. The other objective was to document the morphologic pathology in a sufficiently large series of patients so treated as to cover most, if not all, of the variants which might be expected. It is hoped that from these data the pathogenesis of minimal tuberculosis might become better understood. It is not the purpose of this study to infer that surgical removal of residual disease during chemotherapy was either a necessary or even a desirable procedure in all cases. Patients require management on the basis of the individual. The dynamics of the pathologic process should be carefully weighed while his constitution and the socioeconomic facts are under scrutiny.*

*Note: Dr. Medlar's death and the scattering of his associates due to the closing of Biggs Hospital have left the preparation of the final draft to one of the authors. It was Dr. Medlar's aim to set forth the observations in this group of patients. He did not endeavor to correlate or reconcile his views with those of other pathologists and it would be presumptuous for a clinician or surgeon to speak for him.

Canetti[4] has pointed out the fact that pathologic material hitherto studied has been chiefly from autopsies or surgical specimens removed from patients who were not doing well. It is felt that the material reported here is a valuable supplement to prior studies in that the surgery was elective.

It may be added that Medlar had an opportunity to discuss his field of work with Canetti and that it was Medlar's feeling that they were in essential agreement. Certainly this was true of his attitude toward necrotic residues (caseum) and the fact that they are not eradicated nor their bacillary contents controlled by chemotherapy. Canetti's two concluding paragraphs include the following: (1) "As things are at present, chemotherapy cannot suffice unless the diagnosis can be established before caseation occurs." (2) "In spite of this, the important advances achieved by chemotherapy cannot be overlooked. In addition to its own effects, chemotherapy has considerably enhanced the benefits of rest, and has made surgical resection possible."

One further comment: It was Medlar's concept that as regards its necrotic component at least minimal tuberculosis is essentially a localized process. He felt that any scattered bacilli in other areas, not "protected" by necrotic (caseous) zones, would succumb to chemotherapy, and that surgical excision of the palpable necrotic foci would remove the remaining potential future threat and in effect "cure" the patient. He had even speculated that reversion to a negative tuberculin reaction might be within possibility. The validity of this thesis can only be tested by the lapse of time.

FOLLOW-UP

The health status of this group of patients following discharge from the hospital was felt to be of special interest. A consistent effort was made to secure routine follow-up observations. This has been difficult because the individuals became widely scattered. However, a significant proportion have been seen and have had at least an x-ray of the chest (Table IX).

TABLE IX. FOLLOW-UP DATA

	YEARS AFTER RESECTION					
	1	2	3	4	5	6
Patients observed: 104*	2	18	27	21	20	12
Lost to follow-up after stated year	2†	5	5	2	1†	

*No follow-up—4.
†One death each year.

Two have been lost from the group by death, one in the second postoperative year due to bronchogenic carcinoma of the opposite lung, the other in the fifth postoperative year, due to gangrene of lower extremities.

There has been one "bacteriological relapse" with a positive culture reported once in the fourth postoperative year, a finding not confirmed a month later, nor on re-examination the next year.

One clinical "relapse" occurred during the fifth year, in the lung opposite to the resection, coincident with the finding of recurrent advanced disease in the patient's wife.

SUMMARY

A study of 104 cases of minimal tuberculosis treated by rest, chemotherapy, and surgical excision is reported, together with data from pathologic studies of the resected tissue, and a follow-up report.

Bilateral surgery was performed in 15, or a total of 119 thoracotomies. No deaths resulted from the operations. Major complications occurred in 9 per cent, and were treated successfully; minor complications in 13 per cent, chiefly small temporary air leaks, were followed by full recovery.

Observations on the resected specimens are reported and discussed. The outstanding finding was the presence of necrotic lesions in 103 patients, this being the dominant feature in 83. Bronchial communication was demonstrated in 49, and believed to exist in all necrotic lesions. Cavity formation was demonstrated in 48; open in 14, "filled in" in 30, and largely scar in 4. Pneumonic foci, interpreted as recent bronchogenic spreads, were noted in 10, despite chemotherapy. There was no observed correlation between the duration of chemotherapy and the anatomic pathologic features which varied widely; nor was there a demonstrable causal relationship between chemotherapy and the observed features of the necrotic (caseous) lesions, which had not been eradicated.

The follow-up, although incomplete, gives information on 98 patients for 2 years or more, with an average of 4 years. The only known clinical relapse occurred in the fifth year.

Grateful acknowledgment is made to Dr. A. A. Zavaleta for his interest and help in this study.

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RESECTION OF ONE LOBE AND ONE SEGMENT WITH AN OSTEOPLASTIC THORACOPLASTY

Functional Results

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A COMPLICATION with infection after a pulmonary resection will reduce the function considerably. In order to avoid a postoperative infection in a remaining space, we have considered it essential to reduce the size of the thoracic cavity to fit the remaining lung parenchyma, especially in cases where such complications are frequent. Resection of one segment, in addition to a lobectomy, constitutes an absolute indication for a space-diminishing procedure. The aim of this paper is to report the functional result obtained after such resections when an osteoplastic thoracoplasty is added.

TECHNIQUE

The osteoplastic thoracoplasty is performed as easily in the face-down position as in the lateral position. The first rib may be left in place. The posterior portions of ribs 2 to 5 are resected in increasing lengths downward and fixed posteriorly by nylon sutures through drill holes in the ribs. The most important technical details to prevent a herniation of the lung above the new roof are:

1. To make the second rib as short and straight as possible.
2. To incise the second costal cartilage making it possible to place the second rib close to the mediastinum.
3. The fixation of the posterior end of the second rib to the costovertebral ligament by a nylon suture.
4. The fixation of the first intercostal muscle bundle attached to the second rib to mediastinal tissue.
5. Ribs 3 to 5 are fixed by heavy catgut sutures through drill holes in the divided ribs and then pericostally around the sixth rib.

MATERIAL

Only patients with a normal contralateral lung have been selected for this postoperative study. Ten patients (8 resections on the right and 2 on the

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TABLE I. THE FUNCTIONAL RESULT OBTAINED AFTER RESECTION OF ONE LOBE AND ONE SEGMENT WITH AN OSTEOPLASTIC THORACOPLASTY

CASE	AGE	LUNG TISSUE RESECTED	OBSERVATION TIME	O_2 UPTAKE RIGHT LUNG IN % OF TOTAL	REMAINING O_2 UPTAKE OF THE OPERATED LUNG IN % OF ITS CALCULATED NORMAL VALUE	VENTILATION RIGHT LUNG IN % OF TOTAL	MAXIMAL MOVEMENTS OF DIAPHRAGM (C.M.)	
							RIGHT	LEFT
1	Woman 45	Right upper lobe + sup. segm. right lower lobe	Preop.	43	70	73		
			3 yr. postop.	23	28	35	6	7
2	Man 42	Right upper lobe + ant. basal segm. right lower lobe	Preop.	45	75	52		
			3 yr. postop.	31	41	48		
3	Man 59	Right upper lobe + sup. segm. right lower lobe	Preop.	30	40	30		
			2 yr. postop.	18	20	38	6.5	3.5
4	Woman 46	Right upper lobe + sup. segm. right lower lobe	Preop.	42	67	49		
			4 yr. postop.	41	64	48	5	6
5	Woman 30	Right upper lobe + sup. segm. right lower lobe	Preop.	49	89	57		
			4 yr. postop.	25	31	47	4.5	5
6	Woman 35	Right upper lobe + sup. segm. right lower lobe	Preop.	54	108	66		
			4 yr. postop.	45	87	60	6.5	6.5
7	Woman 34	Right lower lobe + segm. lat. middle lobe	1 yr. postop.	22	26	54	4.5	3.5
8	Woman 60	Right upper lobe + sup. segm. lower lobe + right main bronchus	Preop.	16	18	36		
			1 yr. postop.	39	59	43	4	5
9	Woman 42	Left upper lobe + sup. segm. left lower lobe	Preop.	77	32	75		
			4 yr. postop.	80	27	83	8	6
10	Man 57	Left upper lobe + sup. segm. left lower lobe	Preop.	53	96	55		
			3 yr. postop.	79	29	77	3.5	2

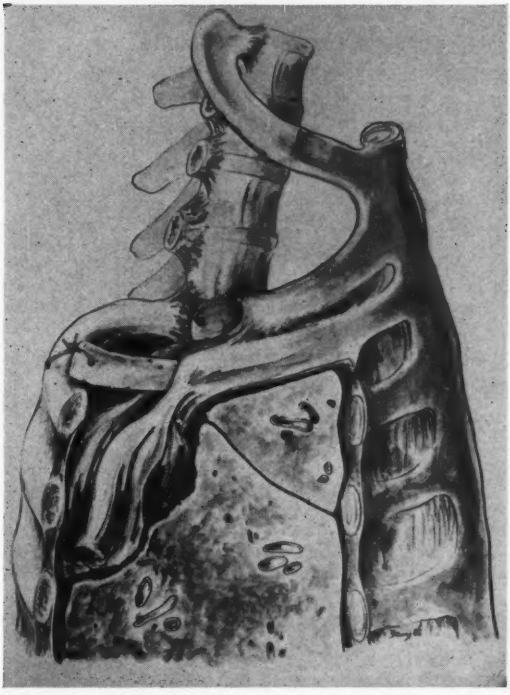

Fig. 1.—Diagram of the osteoplastic thoracoplasty with resection of the posterior parts of ribs 2 to 5 with fixation of the posterior end of the rib 2 by a nylon suture through a drill hole and through the costovertebral ligament. Ribs 3 to 5 are fixed by catgut sutures through drill holes and then pericostally around the sixth rib.

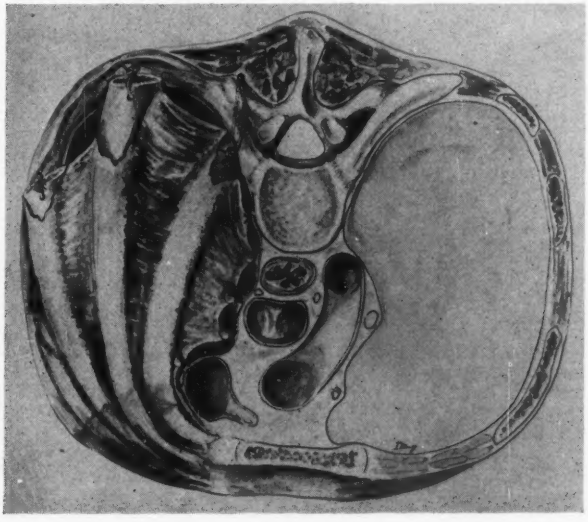

Fig. 2.—Diagram of the osteoplastic thoracoplasty as viewed from above.

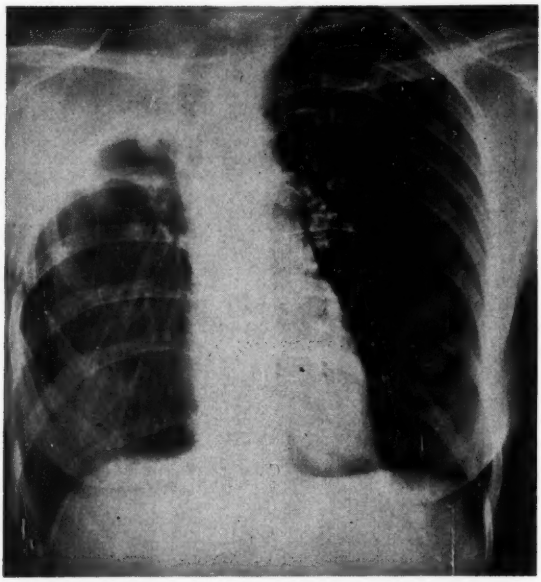

Fig. 3.—Case 1. X-ray film of a 45-year-old woman taken 3 years after resection of the right upper lobe and the superior segment of the right lower lobe plus an osteoplastic thoracoplasty. The patient is working full time as a housewife.

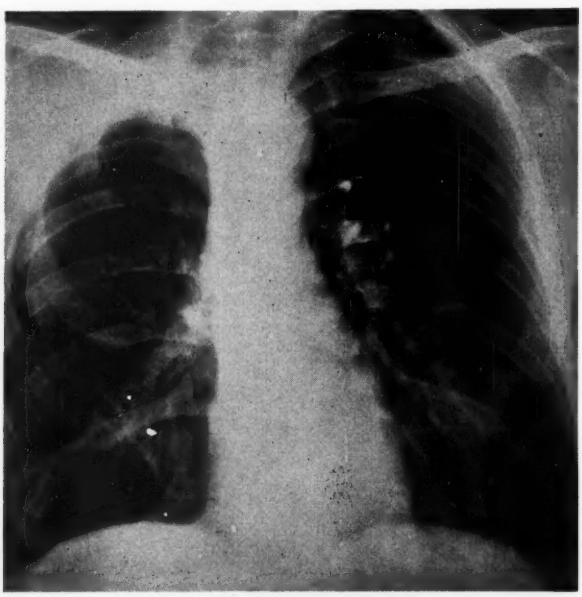

Fig. 4.—Case 2, a 42-year-old man. X-ray film made 3 years after resection of the right upper lobe plus the anterior basal segment of the right lower lobe plus osteoplastic thoracoplasty. Thirty-one per cent of the total of the oxygen uptake comes from the right lung.

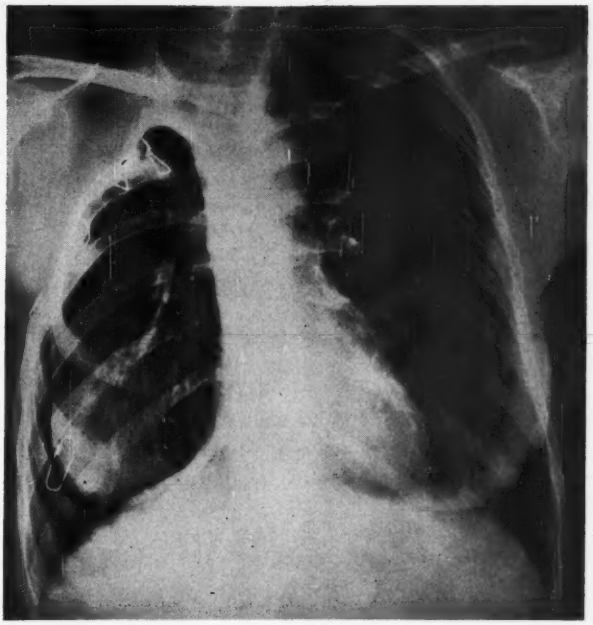

Fig. 5.—Case 5, a 30-year-old woman. X-ray film made 4 years after resection of the right upper lobe plus the superior segment of the right lower lobe. Twenty-five per cent of the total oxygen uptake comes from the right lung. The patient is now working full time as a housewife.

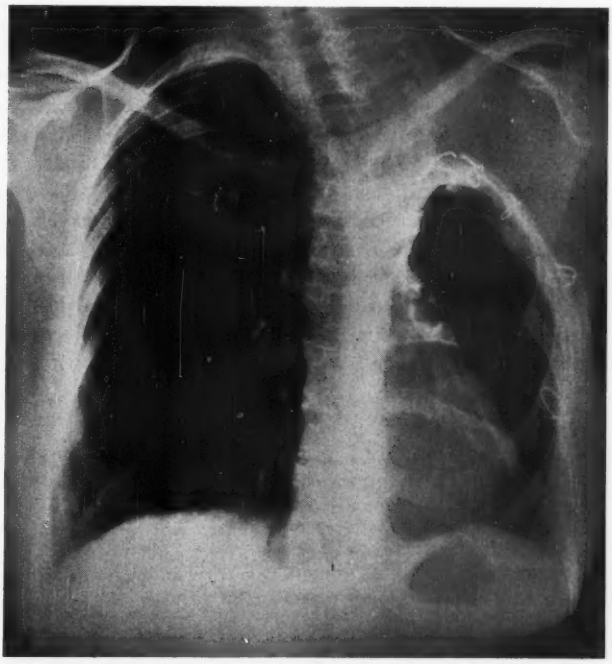

Fig. 6.—Case 9, a 42-year-old woman. X-ray film made 4 years after resection of the left upper lobe plus the superior segment of the lower lobe. Twenty per cent of the total oxygen uptake now comes from the left side as compared with 23 per cent before the resection.

left) have been followed; the function was investigated 1 to 4 years after lobectomy plus segmental resection plus osteoplastic thoracoplasty. All broncho-spirometric investigations have been performed with a Carlens' double lumen catheter. The results obtained are summarized in Table I and shown in Figs. 3 to 6.

DISCUSSION

The resection of a segment in addition to one lobe will cause a further reduction of pulmonary function. Still the remaining function is good enough to recommend the continued use of the described technique. The remaining basal segments on the left side under an osteoplastic thoracoplasty has resulted in an oxygen uptake of 20 per cent of the total in 2 cases which means a remaining function of 27 per cent of the normal left lung (calculated according to Bergan):

$$\text{Reduction in per cent (right)} = 100 \times \left(1 - \frac{r \times L}{R \times l}\right).$$

l and r = per cent oxygen uptake of left and right lung after operation.

L and R = per cent oxygen uptake of left and right lung before operation.

The mean value of the oxygen uptake on the right side after the resection of one lobe and one segment under an osteoplastic thoracoplasty was 31 per cent of the total or 41 per cent of the normal right lung, calculated according to the formula just given. That value means an average decrease of 16 per cent of the oxygen uptake on the right lung for the segment resected besides the lobectomy, as the mean value in 15 cases after right upper lobectomy with osteoplastic thoracoplasty resulted in an oxygen uptake on the right side of 38 per cent of the total, or 57 per cent of the normal right lung.

Thus, the reduction in oxygen uptake after lobectomy plus segmental resection plus osteoplastic thoracoplasty on the right side was 59 per cent of the calculated normal right lung function (52 per cent of the total oxygen uptake). The mean value of the measured reduction of this operation was, in our cases, 30 per cent of the normal right lung function. The difference of 29 per cent was due to the destruction of lung tissue by disease before the operation.

SUMMARY

The functional result obtained after the resection of one lobe and one segment with an additional osteoplastic thoracoplasty is reported.

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THE EFFECT OF PULMONARY RESECTION ON THE COMPLIANCE OF HUMAN LUNGS

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INTRODUCTION

THERE have been several attempts to determine the effect of pulmonary resection on the elastic behavior of the lungs.[1-4] McIlroy and Bates[1] found that compliance was lower in patients following pneumonectomy than among healthy control subjects and thought the difference in elastic behavior might be important in the genesis of dyspnea. The same general observation has been made in patients undergoing less extensive surgery.[2, 3] In the study by Gliedman and his associates[3] volume-pressure measurements were made of a single lung during deflation, following distention to volumes above one liter of gas; the measurements were made while the chest was open, before and after partial resection of the same lung. Lategola and co-workers[4] found that removal of portions of the lungs from dogs altered the combined elastic behavior of the thoracic cage and lungs to an extent which depended primarily on the amount of tissue removed.

In the present study, the elastic behavior of the lungs was measured in patients during interrupted breathing, before and after resection of portions of the lungs; each patient therefore served as his own control. It was expected that changes would occur largely on the basis of a reduction in number of distensible units participating in ventilation, owing either to excision or to injury resulting from the operation. To estimate these changes in lung size, measurements were made of the total lung capacity and its subdivisions.

MATERIAL

One female and 15 male patients, all but 2 of whom had been on active duty with the armed forces, were studied. They ranged from 19 to 64 years

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of age (mean: 33 ± 15). Their pertinent physical characteristics, diagnoses, extent of surgery, and findings in their postoperative roentgenograms of the chest are listed in Table I. With one exception, there were no serious complications during surgery or in the immediate postoperative period. The exception was Patient 10 who had a basilar empyema on the left side which required about 9 weeks to clear.

TABLE I. PHYSICAL CHARACTERISTICS AND CLINICAL DATA OF 16 PATIENTS UNDERGOING RESECTION OF LUNG TISSUE

NO.	SEX	AGE (YR.)	HT. (CM.)	B.S.A.* ($M.^2$)	DIAGNOSIS	SEGMENTS REMOVED	POSTOPERATIVE X-RAY FINDINGS	POSTOPERATIVE INTERVAL (WEEKS)
1	M	39	183	2.00	Granuloma	1	R. diaphragm elevated; r. pleural thickening along lateral wall	4
2	M	44	178	1.95	Tuberculosis	1	L. diaphragm elevated; hydropneumothorax, l. base	8
3	M	21	164	1.90	Tuberculosis	1	Minimal pleural thickening, l. upper chest	7
4	M	24	180	1.92	Granuloma	1	Minimal pleural thickening, l. upper chest	2
5	F	37	168	1.72	Granuloma	1	Minimal hydrothorax, l. base	3
6	M	22	175	1.86	Granuloma	1	Minimal pleural thickening, l. base	5
7	M	27	174	1.96	Granuloma	1	None reported	7
8	M	41	178	1.78	Bronchiectasis	2	R. diaphragm elevated; minimal pleural thickening, r. base	4
9	M	33	180	2.01	Tuberculosis	3	R. diaphragm elevated; minimal pleural thickening, r. base	8
10	M	18	175	1.81	Bronchiectasis	3	Pleural thickening, l. base	13
11	M	20	180	1.86	Bronchiectasis	4	Hydropneumothorax, l. base	8
12	M	19	183	1.97	Bronchiectasis	5	Pleural thickening, l. base	19
13	M	25	170	1.78	Bronchiectasis	6	L. diaphragm markedly elevated; pleural thickening, l. lower chest	11
14	M	21	182	1.88	Bronchiectasis	6	R. diaphragm markedly elevated; pleural thickening, r. base	9
15	M	64	175	2.08	L. bronchial ca.	8†	Mediastinal shift to left; l. lung field obscured; r. lung field normal	8
16	M	51	173	1.97	L. bronchial ca.	8†	None reported	14

*Preoperative values for body surface area calculated from DuBois' height-weight formula: Area = $\text{weight}^{0.425} \times \text{height}^{0.725} \times 71.84$.

†Pneumonectomy (left).

METHOD

Pulmonary compliance, an index of the elastic behavior of the lungs, is the ratio of the change in volume of the lungs to the change in transpulmonary pressure:

$$\text{compliance} = \frac{\text{change in volume in liters}}{\text{change in transpulmonary pressure in cm. } H_2O}.$$

In human beings, intraesophageal pressure is customarily measured instead of intrapleural pressure thereby avoiding the danger of puncturing the lungs. The former measurement offers a reliable index of the pressure applied to the surface of the lungs under specified conditions.[5, 6]

The method is a modification of that used by Stead and associates[7]; it has been described previously.[8] A narrow balloon, 15 cm. long and attached to polyethylene tubing,[9] was passed through the patient's nose to the lower portion of the esophagus. The difference between pressures in the esophagus and mouthpiece was measured continuously by a pressure transducer of the inductance type.*

The patient was seated breathing air until respiration became regular. Then, at the end of normal expiration, he was connected by means of a valve to a spirometer and instructed to inspire deeply. At steps of 250 ml. (ATPS), a solenoid valve† in the inspiratory airway a few inches beyond the patient's mouth was closed automatically; the duration of valve closure varied from 1 to 2 seconds. During these interruptions of air flow, pressures equilibrated quickly throughout the lungs and upper airways so that the oral-esophageal pressure difference was an index of transpulmonary pressure. Volume changes were measured with a rotational transducer attached to the wheel of the spirometer. Pressure and volume signals were amplified and recorded by a direct-writing oscillograph.‡

This technique permits measurement of changes in transpulmonary pressure during interrupted breathing at known volume increments of the lungs. When these variables are plotted on a graph, the slope of the line connecting the points gives the value for compliance. In healthy subjects, this slope is approximately rectilinear over a range of 0.75 to 1.25 L., starting from the functional residual capacity (FRC). In this paper, all values for compliance are based on measurements made during inspiration within this range of volumes.

Functional residual capacity was measured with the Darling open-circuit oxygen technique; a mean value was taken of 2 measurements that agreed within 10 per cent of each other. Vital capacity (VC) was recorded on a spirometer; total lung capacity (TLC) was then calculated from the FRC and inspiratory capacity (IC). All volumes were measured with the patients lying supine and are expressed at body temperature, ambient, pressure, saturated with water vapor (BT PS).

*Made by Mr. Frederick E. Wiedeman, 55 Shattuck Street, Boston, Mass.
†Type 8276-20, 110-volt AC, Automatic Switch Company, Orange, N. J.
‡Sanborn Co., Waltham, Mass.

Limitations of the Technique.—Measurements of pulmonary compliance are based on the assumption that gradients of pressure along the surface of the lungs are either absent or are small and remain unchanged at different stages of the respiratory cycle. Such gradients across the mediastinum or within one side of the chest would reduce the accuracy of intra-esophageal pressures (and also of intrapleural pressures obtained from a single locale) as a reflection of forces applied to the lungs. To test whether pleural pressure gradients are produced by surgery would require simultaneous bilateral pleural punctures with measurements of pressure made over large portions of both lungs, a procedure not undertaken because of its risk to the patient. Although it is likely that some inequalities of pressure did result from surgery, we have assumed that they were small. This assumption was supported in part by the fact that in the 14 patients for whom postoperative x-ray studies taken during deep inspiration were reported, the mediastinum appeared to have undergone little or no displacement; this was so even though the mediastinal structures showed little inflammatory thickening at the time of surgery and were therefore considered to be mobile. In order to reduce the possibility that measurements were affected primarily by pleural abnormalities, we have included only patients whose postoperative roentgenograms showed evidence of little or no pleural thickening. Pleural thickening as well as adhesions might influence compliance both by limiting expansion of the lungs and by creating local rigid pockets over the surface of the lungs in which the pressure would be likely to differ from that found elsewhere in the pleural space.

TABLE II. PULMONARY COMPLIANCE, END-EXPIRATORY TRANSPULMONARY PRESSURE, AND LUNG VOLUMES OF 16 PATIENTS BEFORE AND AFTER RESECTION OF LUNG TISSUE

	COMPLIANCE (L./CM. H_2O)		END-EXPIRATORY ESOPHAGEAL PRESSURE (CM. H_2O)		VITAL CAPACITY (L.)		FUNCTIONAL RESIDUAL CAPACITY (L.)		TOTAL LUNG CAPACITY (L.)	
NO.	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
1	0.18	0.08	−6.8	−7.0	4.84	3.96	3.24	2.86	7.06	5.32
2	0.12	0.14	−4.3	−4.6	4.66	4.88	3.46	2.53	7.29	6.31
3	0.14	0.12	−5.5	−8.0	4.70	4.23	2.62	2.02	6.82	5.49
4	0.21	0.20	−4.2	−5.0	5.44	4.10	2.68	2.70	6.92	5.78
5	0.19	0.19	−3.1	−5.2	4.04	2.81	2.32	—	5.62	—
6	0.19	0.19	−5.1	−4.3	4.97	3.74	2.56	2.32	6.09	5.23
7	0.22	0.18	−5.0	−3.4	5.49	—	2.48	—	6.89	—
8	0.28	0.18	−4.4	−3.5	5.48	2.82	3.34	2.99	7.80	5.33
9	0.10	0.09	−4.2	−7.1	3.88	3.18	1.79	1.57	5.25	4.17
10	0.10	0.08	−7.8	−7.9	3.34	2.73	1.86	1.63	4.36	3.13
11	0.15	0.10	−3.9	−6.7	4.62	3.20	2.45	2.54	6.11	4.94
12	0.20	0.15	−7.1	−7.7	5.25	4.23	2.68	2.52	6.36	5.78
13	0.12	0.08	−3.8	−4.6	3.51	2.55	2.24	1.88	5.25	4.02
14	0.16	0.10	−5.1	−6.3	4.15	2.80	2.77	2.62	5.56	4.34
15	0.17	0.07	−3.2	−5.4	4.07	2.35	4.28	2.28	6.80	3.70
16	0.13	0.08	−2.9	−3.7	3.93	2.07	2.00	1.28	5.48	3.11
Mean	0.166	0.127								
S.D.	0.049	0.048								

RESULTS

All values for pulmonary compliance were based on an average of 3 to 5 measurements; the factors governing variability of measurements of compliance have been described before.[8]

Individual values for compliance before and after surgery are listed in Table II. Preoperatively, most of the group had values which were within a normal predicted range.* The exceptions were Patients 1, 9, 10, and 13 whose compliance appeared to be significantly lowered as a result of disease.

Studies were repeated from 2 to 19 weeks postoperatively (average: 8 weeks). Over this period the interval between surgery and time of study bore no apparent relation to changes in compliance.

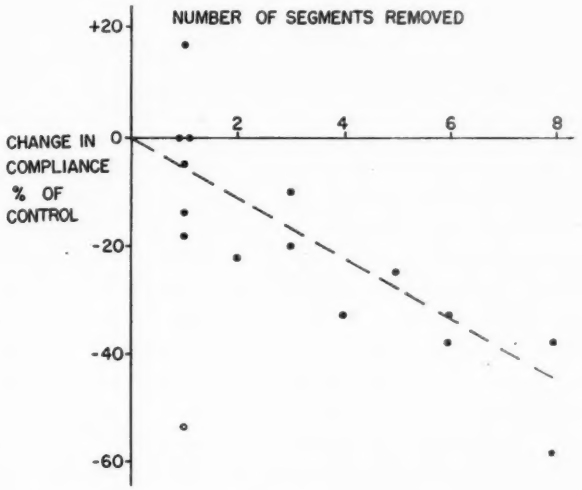

Fig. 1.—Change in compliance expressed as percentage of control is plotted against number of segments removed. The broken line is the correlation that would be expected if the amount of healthy tissue contained in each segment were the same and compliance were not affected by the thoracotomy itself. The measurement represented by the open circle may be an artefact (see text).

In general, there was close correlation between the fall in compliance, expressed as percentage of control values, and the number of segments of lungs removed (Fig. 1).† A striking exception was Patient 7 whose compliance fell 56 per cent in spite of the removal of only one segment from the right apical lobe for a granuloma. This disproportionate reduction of compliance could not be accounted for by an equivalent change in lung volume (Table II); moreover, bronchospirometric studies showed that the contribution of the right lung to total vital capacity fell only 11 per cent following surgery. It is thought that the apparently sharp reduction in compliance was probably due to artefacts.

Correlations were also observed when the postoperative changes (expressed again as percentages of control values) in compliance and vital capacity were

*The statement is based on the prediction formula: pulmonary compliance = 0.00343 × height −0.425. The standard deviation for such a prediction is wide, however, being ±0.035 L/cm. H_2O.[5]

†This correlation probably reflects the amount of healthy tissue, rather than the number of segments, removed.

compared (Fig. 2), as well as when the changes in vital capacity were compared with the number of segments removed (not illustrated).

In general, the FRC was reduced and the end-expiratory transpulmonary pressures became more subatmospheric (Table II); the extent of such changes apparently did not correlate well with changes in pulmonary compliance.

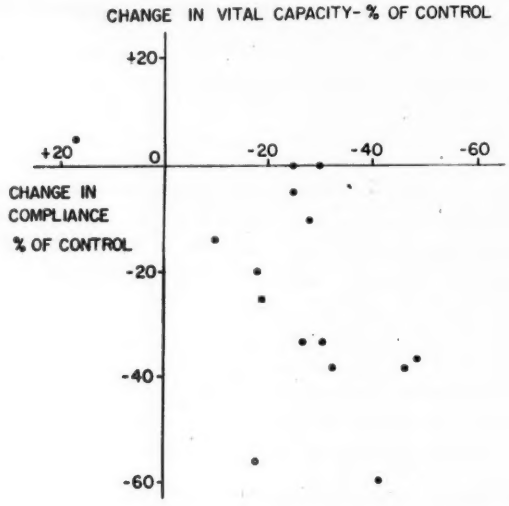

Fig. 2.—Changes in compliance and vital capacity are plotted against each other, both expressed as percentage of control. The measurement represented by the open circle may be an artefact (see text).

DISCUSSION

The patients in this study showed a reduction of pulmonary compliance roughly proportional to the amount of tissue removed. Fig. 1 compares the reduction in compliance with the change that might have been expected if, before surgery, each segment of the lungs contained an equal amount of ventilating tissue and, following surgery, there was no interference with ventilation of the remaining segments. These assumptions cannot be accepted completely. But the fact that the differences between observed and expected changes were random suggests that the thoracotomy itself had little effect on the measurement. It should be emphasized that changes in compliance were generally small compared with those seen in disabling cardiac[10–15] or granulomatous diseases of the lungs.[16] Although the data were insufficient to calculate work of breathing, it is expected to have increased significantly among patients undergoing more extensive surgery.* Because of the difficulty of evaluating disability, no attempt was made to relate it to measurements of compliance.

*The combined flow resistance of the airways and tissues is usually greater in patients following pneumonectomy than in healthy control subjects,[1] thereby contributing to the tendency for an increase in work of breathing.

The most obvious way by which resection of tissue may affect the elastic behavior of the remaining lung is to reduce the number of units participating in ventilation. In the absence of surgery, other circumstances which reduce the effective size of lungs by infiltration, collapse, or obstruction, will have a corresponding effect on pulmonary compliance. Naturally, the reduction in compliance after surgery will be exaggerated if portions of the remaining lung are unable to expand because of airway obstruction, changes in mobility of the thoracic wall, or pleural reaction and thickening.

Compliance is usually expressed as the ratio of changes in volume to changes in pressure in the range of tidal breathing, starting from the FRC. Since these volume-pressure relations vary at different levels of inflation, it is also useful to relate measurements of compliance to the total volume of gas in the lungs. This has been done in Figs. 3 and 4 in which the vertical axis refers to total volume of gas in the lungs and the horizontal axis refers to transpulmonary pressure; the volume at the lowest point on each curve is the FRC. The ratio of the FRC to the corresponding transpulmonary pressure is an index of the over-all compliance of the lungs *below* the range of volume at which spontaneous breathing occurs, that is, between the volume and pressure at end-expiration and zero volume, zero pressure. This ratio gives information about the elastic behavior of the lungs which is not obtained from measurement of the FRC alone. Following surgery, the ratio fell among 12 of the 14 patients from whom such data were obtained (Table II), usually owing both to a decrease in FRC and an increase in distending pressure. The reduction of FRC postoperatively cannot be related in a simple way to the number of segments removed, for there is evidence that the gas volume of the remaining tissue changes with time.[2, 17–19] Also, there is no reliable means of estimating to what extent the volume of individual air spaces may be modified following surgery. However, if esophageal pressure is assumed to be a valid index of pleural pressure, pertinent information on changes affecting air spaces becomes available. The esophageal pressure enables us to follow accurately any change in the *stress* applied to these units. For example, the data of Patient 13 in Fig. 3 show that transpulmonary pressure (stress applied to individual air sacs) compared at the extremes of tidal breathing was only slightly changed at the time of study following resection of 6 segments. Despite the reduction in FRC postoperatively, the volume of individual units is therefore not likely to have changed significantly. In general, however, it was more common for transpulmonary pressure to increase following such extensive surgery. An example is Patient 14 whose data are shown in Fig. 4. Before surgery, average end-expiratory and end-inspiratory transpulmonary pressures were 5.1 and 9.2 cm. H_2O; following surgery they changed to 6.3 and 12.0 cm. H_2O. Had the latter pressures been applied to the intact lungs before surgery, the total volume of gas in the lungs during spontaneous breathing (on the basis of the volume-pressure curve) would have ranged from approximately 3.0 to 3.9 L., rather than from the actual values of 2.8 to 3.4 L. It

follows that the volume of individual units also would have been greater. On the same basis, it may be assumed that postoperatively there was an increase in volume of the remaining units of tissue with respect to their volume preoperatively. To what extent the increased stress and accompanying change of volume may in time alter the mechanical function of adult human lungs is

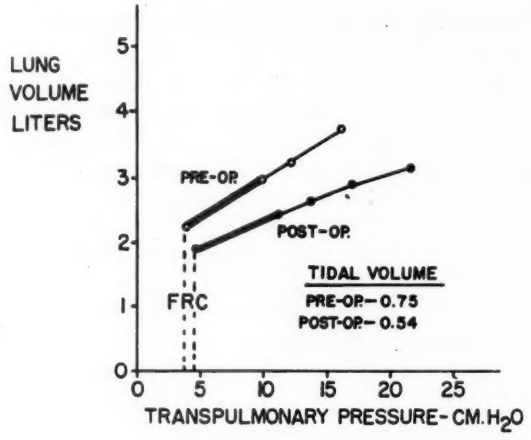

Fig. 3.—Total lung volume is plotted against transpulmonary pressure before and after resection of 6 segments. The heavy line indicates tidal volume. See text for details.

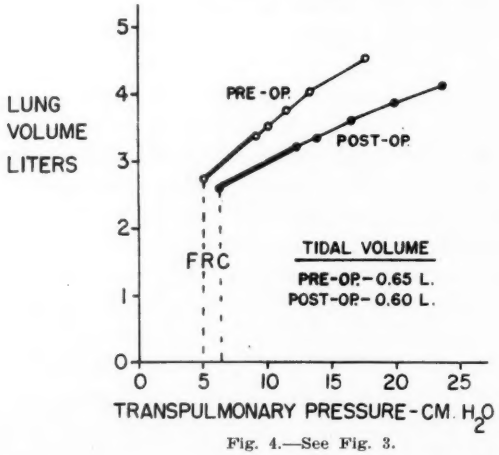

Fig. 4.—See Fig. 3.

not certain. Rienhoff and his associates,[17] 6 months following pneumonectomy in dogs, could find no histologic evidence of damage to the elastic tissue or to other structural components of the alveoli. Longacre and Johansmann[18] did find a reduction in transpulmonary pressure of the remaining lung of 1 dog 4 years after pneumonectomy and concluded that the elastic recoil of the

lung had diminished. No measurements of volume were reported, although the description of the lung at autopsy suggests that its volume had increased significantly during the interval.

SUMMARY AND CONCLUSIONS

Pulmonary compliance was measured in 16 patients before and after partial resection of the lungs. The measurements were made during interrupted breathing while the patients were seated; intraesophageal pressure was used as an index of the force applied to the surface of the lungs. It was found that the pre- to postoperative change in compliance, expressed as percentage of control value, correlated closely with the number of segments of tissue removed. Almost as close was the correlation between changes in compliance and vital capacity. In general, the FRC was reduced following surgery while intraesophageal pressure became more subatmospheric. The reduction in compliance was ascribed to reduction in number of elastic units participating in ventilation.

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MALIGNANT PLEURAL MESOTHELIOMA

A Case Report With Autopsy Findings

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PRIMARY malignant tumors of mesothelial-lined structures are exceedingly rare, and indeed, there is considerable controversy as to whether primary tumors of these spaces do occur. Godwin,[1] Tobiassen,[2] and McCaughey[3] have recently published comprehensive reports reviewing the literature and their personal experience with these tumors. The present report deals with a patient in whom a tumor of the parietal pleura was discovered incidentally before any symptoms ascribable to it had occurred. The tumor was already too extensive for complete removal and the patient died one year later due to widespread local growth. This case illustrates well the variation of histologic structure that can occur in malignant pleural tumors and is one more example in which the evidence appears to be conclusive that the tumor arose as a primary neoplasm in the pleural cavity. The report also contains a brief analysis of the controversy surrounding these tumors.

CASE REPORT

St. Mary's Hospital, No. 4760. A 43-year-old white man was admitted to St. Mary's Hospital in September, 1955, for investigation of an abnormal shadow found on x-ray studies of the chest. Three days previously while working he had felt an acute pain in his left chest. Roentgenograms of the chest in the outpatient department revealed a vertical nonpathologic fracture of the posterior arc of the tenth left rib and a discrete shadow in the right lung field. The patient's general health had been good and except for the left chest pain he had no complaints. The family, environmental, and past history were noncontributory.

Physical examination revealed no abnormal findings except tenderness over the tenth left rib posteriorly, and a positive "spring test." Temperature, pulse, and respiration were normal. The blood pressure was 130 systolic, 80 diastolic.

Examination of the blood revealed normal values. Urine analysis was negative. Sputum culture for routine pathogens and for acid-fast bacilli, and cytologic examinations of the sputum for malignant cells were negative. Roentgenographic examination of the chest (Figs. 1 and 2), on admission showed a homogeneous shadow, 5 cm. in diameter, located peripherally in the right lung field at the level of the fourth interspace. The shadow was pyramidal in shape with a broad base peripherally. It was sharply

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demarcated. A few linear opacities were present between the shadow and the right costophrenic sinus. Bronchography and diagnostic pneumothorax showed that the shadow was not related to the bronchial tree, lung parenchyma, or visceral pleura. Bronchoscopy revealed normal findings. A gastrointestinal series, barium enema, and intravenous pyelogram revealed normal findings.

A right thoracotomy was performed through the sixth intercostal space. A sessile tumor, 5 cm. in average diameter, was found on the parietal pleura at the level of the fourth interspace in the midaxillary line. The tumor was firm, slightly movable over the underlying subpleural structures, and had a nodular surface. The visceral pleura was adherent to the surface of the tumor by fine adhesions. No mass or tumor could be palpated in the visceral pleura or in the lung. A number of small discrete nodules were

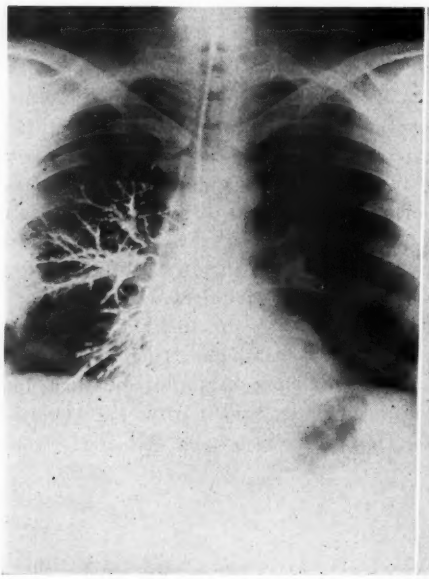

Fig. 1.

Fig. 2.

Fig. 1.—Preoperative roentgenogram of chest combined with bronchogram and diagnostic pneumothorax. The compressed right lung is outlined by the *dotted line*. A peripherally located tumor shadow is present in the right lung field. This does not follow the collapsed lung and does not distort the bronchial tree.

Fig. 2.—Preoperative lateral roentgenogram of chest. A tumor shadow is clearly seen midway between the sternum and vertebra in the mid-thorax (↗). The diaphragmatic nodules are visible in the anterior cul-de-sac (↗↗). A small amount of pleural effusion is present in the posterior cul-de-sac (↑).

present over the diaphragmatic pleura and inferior pulmonary ligament. There was no obvious lymphadenopathy. A block excision of the large tumor, together with the underlying segments of the fourth and fifth ribs, was performed. The pleural seedings were too extensive for complete removal. The postoperative course was uneventful. Review of the preoperative roentgenograms showed a small shadow in the right costophrenic sinus (Fig. 2) corresponding to the diaphragmatic nodules. The patient was discharged after 5 weeks to be followed in the outpatient department at monthly intervals.

He returned to work and was in good health with no complaints until August, 1956. Roentgenograms of the chest taken in July were unchanged from the postoperative films. In August, he complained of some exertional dyspnea and of stabbing pains in the midportion of the back. The pain and dyspnea gradually became more severe, necessitating readmission to hospital on Sept. 21, 1956. Physical examination revealed the patient to

be poorly nourished, slightly cyanosed, and in respiratory distress. There was dullness to percussion over the entire right chest. He was afebrile, but had a rapid, irregular pulse of 160 per minute. The hemoglobin content of the blood was 16 grams per cent and the white blood count was 17,300. Roentgenograms of the chest (Fig. 3) showed a large mass occupying the lower half of the right lung field, the upper limit of which was sharply demarcated and slightly convex upward. A small pleural effusion was present in the lateral part of the right upper hemithorax. The body of the eleventh dorsal vertebra was slightly wedged, and structural changes suggested metastatic involvement. The patient's condition gradually worsened and he died on Oct. 2, 1956.

Fig. 3.—Postoperative (8 month) roentgenogram of the chest. A large tumor occupies the lower one half of the right lung field. A homogeneous shadow along the right axillary line indicates pleural effusion.

Pathologic Findings.—

1. *Surgical specimen* (S.55-1577): Two 6 cm. long segments of rib were covered on one surface by parietal pleura. From this surface a polypoid tumor, 5 cm. in average diameter, was raised 3 cm. above the level of the surrounding pleura. On cross-section (Fig. 4) the tumor appeared to be circumscribed and localized. Histologic examination showed the free surface of the tumor to be covered by dense collagen. The tumor consisted of large regular cells, with a central nucleus, and a large rim of eosinophilic cytoplasm (Fig. 5). In some areas, the cells were arranged in cords and trabeculae, in others they lined small clefts or tube-like spaces, sometimes with papillary infoldings (Fig. 6). A few of the cells contained vacuoles. The cells were supported by a loose reticular stroma. Mitotic figures were not found. The tumor, although not encapsulated, did not penetrate as far as the periosteum of the ribs and did not invade the tissues of the intercostal space. The pathologic diagnosis was mesothelioma, right parietal pleura.

2. *Autopsy* (A.56-94): (a) Gross examination: The greater portion of the right hemithorax was occupied by a large mass (Fig. 7) which was continuous with the diaphragmatic pleura and the parietal pleura of the lateral wall. In the upper part of this hemithorax, a small pleural space, containing 200 c.c. of clear fluid, remained. Small

tumor nodules were scattered over the right mediastinal pleura. The upper part of the large mass was compressed lung covered by unremarkable visceral pleura. When the mass and lung were removed, a sheet of tumor tissue was found covering the posterior parietal pleura. The lung and attached mass weighed 1,700 grams. Section through this (Fig. 8) showed the lung to be completely atelectatic and displaced toward the hilum by the tumor which measured 20 by 20 cm. There was a line of demarcation between the lung and the tumor, which did not appear to invade the lung parenchyma. No enlarged lymph nodes were found. The bronchial tree showed no tumor or ulceration. Tumor extended from the layer found on the posterior parietal pleura into the right eleventh rib and the body of the eleventh dorsal vertebra.

The left pleural cavity was free of adhesions or excess fluid. There was a healed fracture of the tenth left rib. The left lung weighed 650 grams. There was one 0.5 cm. nodule on the visceral pleura of the anterior part of the upper lobe. The parenchyma of this lung showed congestion and edema but no gross evidence of tumor. There were small gray tumor nodules scattered over the pericardial and epicardial surfaces but the

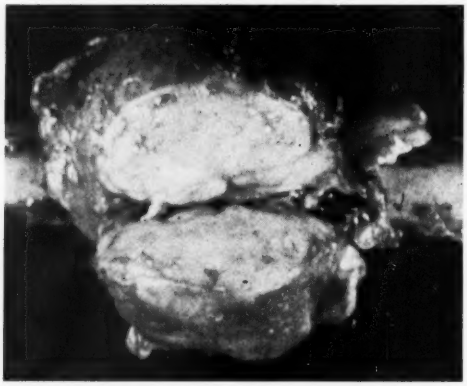

Fig. 4.—Resected tumor and rib. The tumor has been bisected showing its apparent circumscription.

pericardial sac did not contain excess fluid. The heart weighed 325 grams. Section through the epicardial nodules showed invasion into the myocardium. One nodule extended completely through the myocardium to form a small polypoid mass projecting into the left ventricle. The peritoneal cavity was normal except for a 2.5 cm. tumor nodule on the parietal peritoneum, and a smaller nodule on the serosa of the mid-jejunum. There was no other significant gross finding, although all organs were carefully examined for evidence of a small, primary tumor.

(b) Microscopic findings: Tumor was present in all areas noted grossly and in addition there was a small metastatic tumor nodule in the left adrenal cortex. Tumor encased the right lung but did not appear to invade into the parenchyma. The tumor showed a basically sarcomatous pattern (Fig. 9) with fusiform cells arranged in interwoven fascicles and supported by a small amount of fine fibrillar stroma. Mitotic figures were frequent. In some areas the pattern varied, the cells being larger, less fusiform, sometimes multinucleated and occasionally vacuolated. A few areas resembled those in the surgical specimen, with cells lining clefts or tubelike spaces (Fig. 10); this pattern was found predominantly near free surfaces.

Pathological diagnosis: Diffuse mesothelioma of the right parietal pleura with extension to the right visceral and mediastinal pleura, pericardium, epicardium, myocardium, endocardium, left visceral pleura, eleventh rib, eleventh dorsal vertebrae, parietal and visceral peritoneum, and metastasis to the left adrenal gland.

Fig. 5.

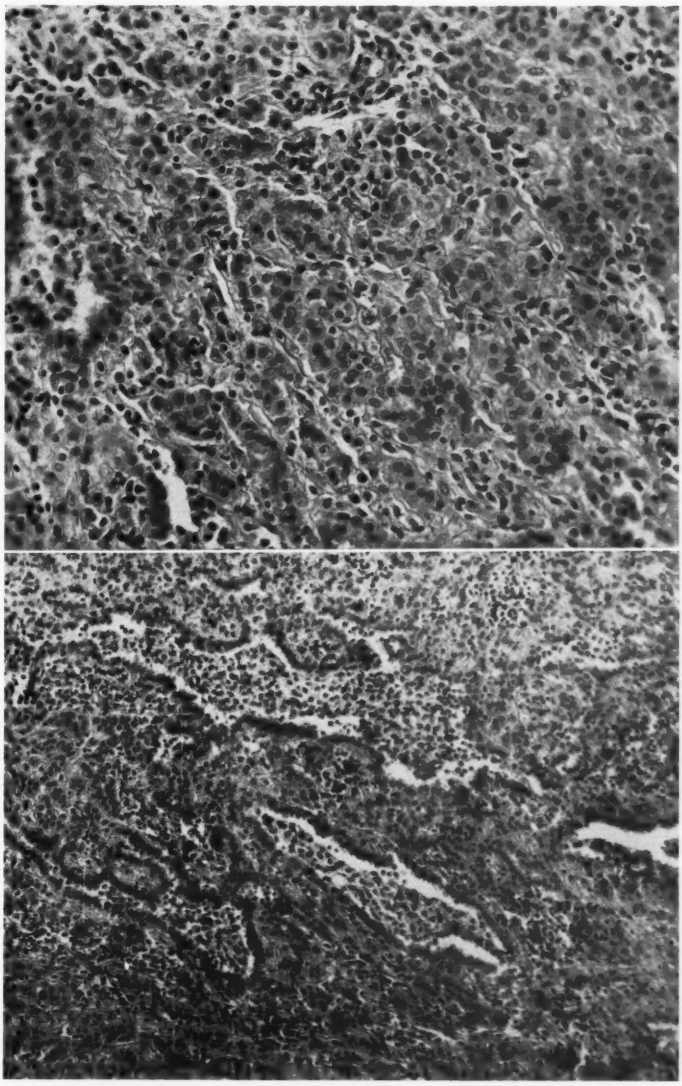

Fig. 6.

Fig. 5.—Photomicrograph of the surgical specimen showing clefts and gland-like spaces lined by epithelium-like cells. (Hematoxylin and eosin; ×100; reduced ¼.)

Fig. 6.—Photomicrograph of surgical specimen showing tubes of large epithelium-like cells and a few clefts. (Hematoxylin and eosin; ×200; reduced ¼.)

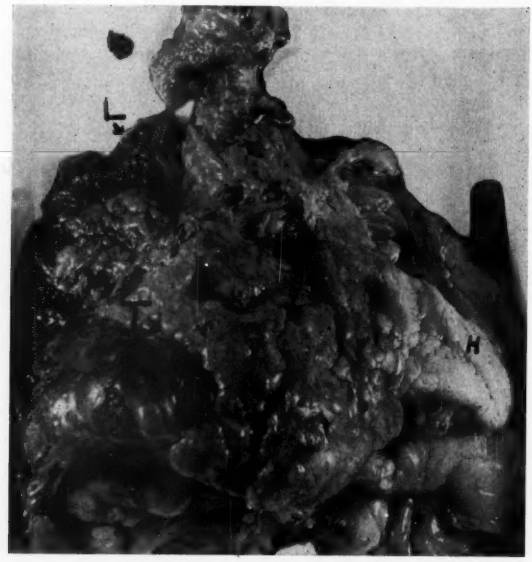

Fig. 7.—Photograph of the thoracic contents at autopsy. A large mass (*T*) occupies the major portion of the right hemithorax. The compressed right lung (*L*) is seen above this. Tumor nodules can be seen on the epicardium of the heart (*H*) and on the mediastinal pleura and pericardium (*P*).

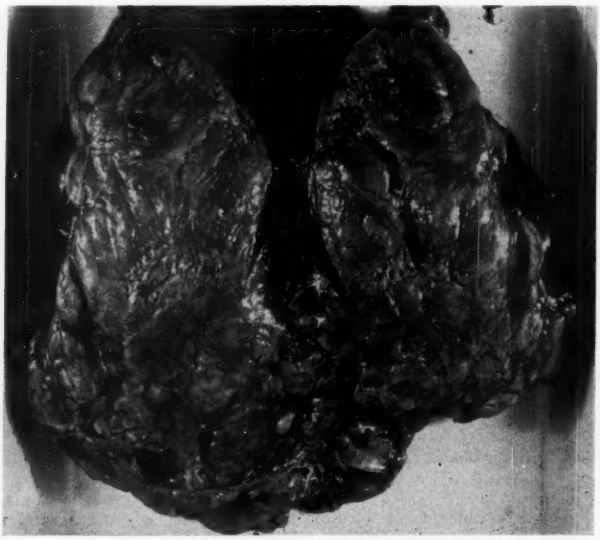

Fig. 8.—Photograph of bisected tumor mass (*T* in Fig. 7). The bisected atelectatic right lung is at the *top* and the diaphragmatic surface at the *bottom* of the photograph. There is a sharp line of demarcation between the tumor and the lung.

Fig. 9.

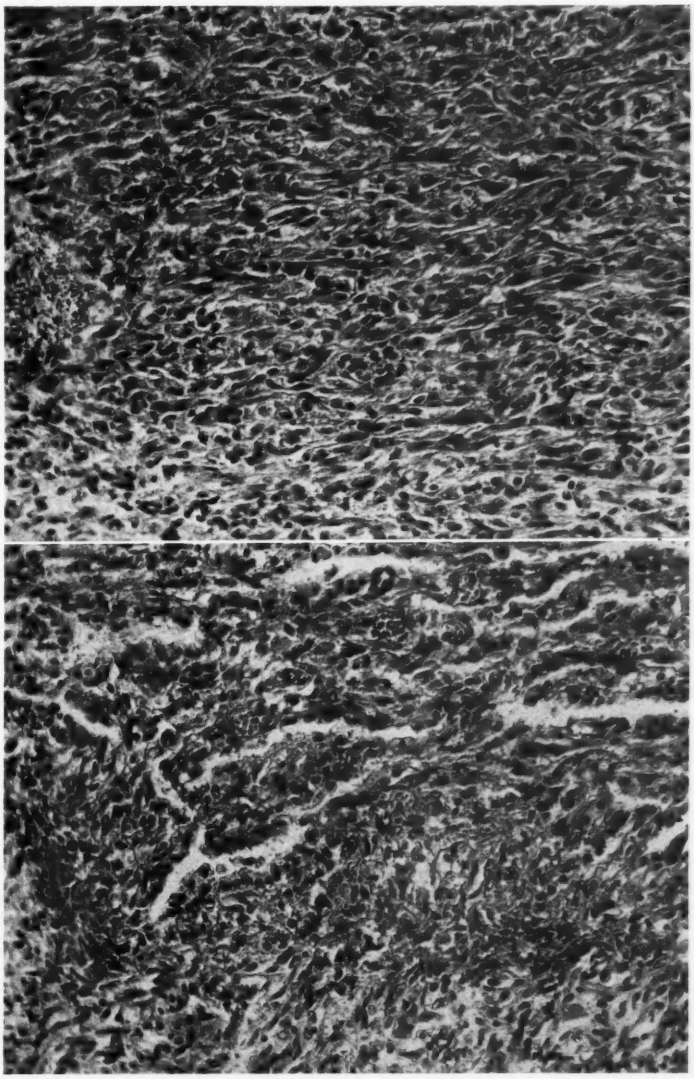

Fig. 10.

Fig. 9.—Photomicrograph of tumor at autopsy showing sarcomatous pattern. (Hematoxylin and eosin; ×200; reduced ¼.)

Fig. 10.—Photomicrograph of tumor at autopsy. An area near a free surface in which the pattern resembled that seen in the surgical specimen (see Figs. 5 and 6). (Hematoxylin and eosin; ×200; reduced ¼.)

DISCUSSION

Stout[4] has proposed a division of primary tumors of mesothelial lined cavities into (1) a solitary fibrous variety, benign or malignant, and (2) a diffuse malignant variety. The solitary fibrous variety they described as being sharply circumscribed with the benign type being pedunculated, and the malignant type having a broad attachment to the pleura. Histologically, both subtypes of the solitary variety have a fibrous structure, the malignant type being more cellular and less differentiated. The diffuse malignant variety appears as a diffuse nodular pleural thickening which spreads widely and rapidly to invade the adjacent tissues and which may penetrate the diaphragm to invade the peritoneum. It almost never metastasizes. This variety shows a varied histologic structure. It may consist predominantly of spindle cells resembling a fibrosarcoma, predominantly of epithelium-like structure, with swollen cells arranged in cords or lining tubes, or it may consist of a mixture of the two. The fact that the localized variety may at times have a histologic structure similar to the diffuse reduces the possibility of always achieving a sharp distinction between the two groups.

The present case illustrates some of the pathologic features of the malignant variety of pleural tumors, although it is difficult to classify it as to solitary or diffuse. The surgically removed specimen gave rather a false impression of benignity. The tumor was raised above the pleural surface and seemed sharply circumscribed. Histologically, it had an epithelium-like structure with cells arranged in tubular and papillary fashion. There were no fibroblastic or sarcomatous features. At autopsy, the tumor showed a predominantly sarcomatous pattern with only rare foci of epithelium-like structure, usually in relation to free surfaces. There was widespread involvement of adjacent structures, evidence of spread through the diaphragm, and one microscopic metastatic focus in an adrenal.

The tumor was discovered incidentally before any symptoms had appeared. Combined bronchoscopy and diagnostic pneumothorax clearly demonstrated the extrapulmonary location of the lesion. In spite of this presumably early stage, the tumor had spread to the diaphragmatic pleura so that, at exploration, total removal was not considered feasible. For 9 months after operation the patient's general health remained good and chest roentgenograms showed no change; during the last 3 months of life, the tumor growth, as far as can be judged by the roentgenograms and autopsy findings, must have been extremely rapid. The cause of the changes in the growth rate of tumors is unknown.[5] The surgical procedure seems too remote to be implicated, although surgery has been accused of accelerating the rate of spread of pleural tumors. The really significant feature of these tumors is the extent of their local growth and the paucity of metastases; in the present case, although the tumor had grown into the cavity of the left ventricle, the only distant metastasis was microscopic. The poor survival rate, only months from the onset of symptoms in most cases, and the rarity of distant metastases, coupled with the failure of chemotherapy or radiation therapy to affect these tumors, indicate, we believe, that as radical

a surgical procedure as technically feasible should be performed in the hope of salvaging an occasional patient. In the present case, a pleuropneumonectomy might have offered this man a better chance.

The controversy concerning the origin of pleural tumors centers around the necessity of explaining the two types of tissue, epithelial and fibrous, sometimes found in these tumors. To explain this duality, an origin from the lining layer of coelomic cavities, the mesothelium, was suggested.[6] Coelomic cavities arise from the splanchnopleure, a combination of the entoderm and splanchnic mesoderm.[7] It has been postulated that the lining layer is a separate distinct layer rising from entoderm derived cells. There is, however, a difference of opinion as to whether the lining layer in coelomic cavities is really a separate layer distinct from its suporting connective tissue. Those who feel that such a layer does exist liken it to epithelium and feel that a specific tumor can arise from it.[1, 4] Those holding the opposite view believe that the lining layer merely is a flattening of the fibroblasts of the supporting connective tissue and naturally deny that any tumor can arise from what they consider to be nonexistent.[8] Embryological data and results of tissue culture studies have been cited as evidence for a distinct mesothelial layer but are far from conclusive. Experimental evidence concerning a mesothelial layer is contradictory. Williams[9] studied the healing of wounds of the peritoneum in rabbits and concluded that the lining layer re-forms from the underlying supporting connective tissue, while Cameron and his co-workers[10] studied the healing of the peritoneum in rats and felt that the lining layer regenerated from clumps of "mesothelial" cells implanted on the wound surface from the surrounding peritoneum. Experiments on the synovial membrane,[11, 12] which morphologically resembles the pleura and peritoneum, suggest that it does not have a distinct lining membrane, but that the synovial lining cells are formed from the underlying connective tissue. It would thus appear that at present there is insufficient evidence to state unequivocally whether a distinct layer, the "mesothelium" does exist in coelomic cavities. If such a layer does exist, its reaction to injury does not appear to be similar to that of the epithelium of the skin or mucous surfaces. When the lining cells of the pleura, peritoneum, or synovial membrane react to an irritant they become more numerous and assume a form which some morphologists classify as epithelial. This does not necessarily indicate embryological predeterminism, but could be related to a decrease in distorting forces so that the cells assume more nearly the circular form of free cells. It appears to be impossible to come to a firm decision on the basis of data available.

Willis[8] considers that mesotheliomata do not exist. The sarcomatous types, described by Stout, he feels are ordinary fibrosarcomas and those showing epithelial structure he thinks are usually metastases from a small, undiscovered carcinoma. Although many of the reported cases may have been fibrosarcomata or metastatic carcinoma, there would now appear to be some cases which justify the conclusion that rare primary tumors, which are not metastases and which have histologic features distinct from ordinary fibrosarcomata, may arise in the serous cavities. There is little doubt that the tumor reported here arose as

a primary neoplasm in the pleural cavity. Careful search at autopsy failed to reveal any other possible primary site. As the tumor removed at operation had almost no fibroblastic component, consisting of cells resembling epithelial cells, and the tumor at autopsy had in the main a sarcomatous pattern with only a few epithelial-like areas, we feel that this case demonstrates clearly that the epithelial-like and sarcomatous components found in primary tumors of serosal cavities represent morphologic variations of the same neoplasm. There does not appear to be enough evidence to decide unequivocally whether these are truly primary tumors of a specialized structure, the "mesothelium," with an embryonic potential to produce both epithelial and fibrous tissue elements, or are fundamentally fibrous tissue tumors in which cells with an altered form, resembling epithelial cells, may be found. Malignant synovioma which histologically closely resemble these tumors are accepted as fundamentally sarcomatous. The term "mesothelioma" is then probably not fully justified from an academic point of view. From a practical point of view it seems to serve a purpose to denote tumors arising primarily in the serous cavities which have a varied histologic structure, and which, when malignant, have a rather uniform growth pattern with extensive invasion but with little tendency to metastasize.

SUMMARY

A case of a primary malignant tumor of the parietal pleura in a 43-year-old man is presented. A thoracotomy with removal of the main tumor was performed but diaphragmatic pleural implants precluded complete removal. The patient died one year later and autopsy showed widespread local invasion and one microscopic metastasis in an adrenal gland. Histologically, the tumor removed at operation showed an epithelium-like structure and that at autopsy mainly a sarcomatous pattern. An analysis of the controversy surrounding primary tumors of the serosal cavities is presented.

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SCALENE LYMPH NODE BIOPSY, CYTOLOGIC STUDIES, AND OTHER DIAGNOSTIC METHODS IN INTRATHORACIC DISEASE

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IN THE PAST several years, scalene lymph node biopsy has achieved general recognition as a useful adjunct in the diagnosis of intrathoracic and, at times, intra-abdominal disease. Following the initial report by Daniels in 1949,[1] several authors have reported their results with this technique.[2-8] To date, however, only a few of these reports have included a comparison between the results of scalene node biopsy and those of exfoliative bronchial cytology in an appreciable number of cases. It was, therefore, decided to carry out this comparative study, and, in addition, to review the relative effectiveness of the various techniques now commonly used in this hospital in the diagnosis of intrathoracic disease, namely x-ray studies, bronchoscopy, scalene node biopsy, and exfoliative cytology. When the study originally planned was completed, however, exfoliative cytology was found distinctly less useful as a diagnostic aid in this hospital than has been reported elsewhere.[6, 10-14] The original review was, therefore, expanded in an attempt to explain this discrepancy. It is felt that this latter part of the study may be of particular interest to those in institutions where the volume of cytologic studies does not warrant a separate subdivision of cytology in the laboratory.

MATERIAL AND METHODS

All cases were reviewed from the years 1951 to 1958 in which scalene lymph node biopsy was performed and tissues were submitted to the pathology laboratory. The clinical records were studied with particular attention to the pathologic diagnoses, the x-ray findings, the results of bronchoscopy, the reports of any bronchial cytologic studies performed, the operative findings if thoracotomy was performed, and the final clinical diagnosis in each case. Cases were included in this series only if the node biopsy was done to assist in the diagnosis of intrathoracic disease. In this group, there were a few cases in which extrathoracic malignancy or other disease had been diagnosed previously, but the node biopsies were performed because the etiology of the intrathoracic disease was still in doubt. Cases in which the chief complaint was enlarged cervical

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nodes or the presence of generalized lymphadenopathy of undetermined etiology were excluded. In most of the cases, the nodes removed were not palpable before operation. All cases in which tissue was submitted to the laboratory, regardless of the number of nodes identified, were included.

After selection of cases for the series by these criteria, all of the bronchial cytologic preparations that were previously reported as negative from these selected cases were reviewed. This slide review was made without knowledge as to the final clinical diagnosis in the case.

All available hospital personnel in any way concerned were then questioned as to the exact procedure they followed in the collection, transportation, or processing of the cytologic material.

RESULTS

One hundred cases of scalene lymph node biopsy were found that met the above criteria. In 62, there was a final clinical diagnosis of intrathoracic neoplasm based on a histologic study of the tissue removed at bronchoscopy, thoracotomy, or scalene node biopsy. Most of the cancers were of bronchogenic origin but a few were metastatic to the lung and scalene nodes from other sites. In the 38 noncancerous cases, there were 11 of sarcoid, 4 of tuberculosis, and 23 of miscellaneous nonneoplastic diseases.

In all of the 100 cases, there were abnormal findings in chest roentgenograms before scalene node biopsy. Depending on the location of the lesion and its lymphatic drainage,[3, 4, 15] scalene node biopsies were performed on the right side in 72 cases, on the left in 23 cases, and bilaterally in 5 cases. The pathologic diagnoses on the scalene biopsy specimens are shown in Table I. The final diagnoses in cases with negative nodes are seen in Table II. A comparison between the radiologic diagnosis and the pathologic diagnosis on the scalene node biopsy specimen from each case is seen in Table III, while a comparison between the radiologic diagnoses and final clinical diagnoses is seen in Table IV.

TABLE I. PATHOLOGIC DIAGNOSES IN 100 CASES OF SCALENE LYMPH NODE BIOPSY

NEGATIVE	MALIGNANT TUMOR	SARCOID	TUBERCULOSIS	MISCELLANEOUS
50	35	11	3	1

TABLE II. FINAL CLINICAL DIAGNOSES IN 50 CASES OF HISTOLOGICALLY NEGATIVE SCALENE LYMPH NODE BIOPSY SPECIMENS

MALIGNANT TUMOR	SARCOID	TUBERCULOSIS	MISCELLANEOUS BENIGN DISEASES
30	0	4	16

A positive diagnosis was made on examination of the lymph nodes in 50 per cent of all of the cases. For those cases in which a diagnosis of intrathoracic neoplasm was eventually established, positive scalene nodes were found in slightly more than 60 per cent of the cases.

TABLE III. CORRELATION OF PATHOLOGIC DIAGNOSES ON SCALENE NODES WITH ROENTGENOLOGIC DIAGNOSES IN 96 CASES

PATHOLOGIC DIAGNOSES	ROENTGENOLOGIC DIAGNOSES			
	TUMOR	SUSPICIOUS	SARCOID	MISCELLANEOUS
Tumor	18	11	0	5
Negative	20	13	0	16
Sarcoid	2	2	1	4
Miscellaneous	1	0	0	3
Totals	41	26	1	28

TABLE IV. CORRELATION OF ROENTGENOLOGIC AND FINAL CLINICAL DIAGNOSES IN 96 CASES

FINAL DIAGNOSES	ROENTGENOLOGIC DIAGNOSES			
	TUMOR	SUSPICIOUS	SARCOID	MISCELLANEOUS
Tumor	37	20	0	7
Sarcoid	2	2	1	2
Miscellaneous	2	4	0	19
Totals	41	26	1	28

Bronchoscopy was performed in 63 cases. In 45 of them a histologic diagnosis of intrathoracic tumor was finally made (Table V). The bronchoscopic diagnoses used in this tabulation were those dictated in the operative note by the bronchoscopist before pathologic examination of biopsy specimens. Biopsies were, however, performed at the time of bronchoscopy on all areas suspicious of neoplasm.

TABLE V. CORRELATION OF PATHOLOGIC DIAGNOSES ON SCALENE NODES WITH BRONCHOSCOPIC DIAGNOSES IN 63 CASES

PATHOLOGIC DIAGNOSES	BRONCHOSCOPIC DIAGNOSES		
	NEGATIVE	SUSPICIOUS	TUMOR
Negative	13*	5†	19‡
Tumor	5	3	14
Sarcoid	2	0	1
Tuberculosis	0	0	1

*The final clinical diagnosis was tumor in 5, tuberculosis in 1, and miscellaneous in 7 cases.

†The final clinical diagnosis was tumor in 2, tuberculosis in 1, and miscellaneous in 2 cases.

‡The final clinical diagnosis was tumor in 16, tuberculosis in 1, and miscellaneous in 2 cases.

The bronchoscopist reported the presence of tumor in almost 70 per cent of the cases of intrathoracic neoplasm, while suspicious findings were noted in an additional 10 per cent of cases. On the other hand, out of 15 cases of nonmalignant disease, the bronchoscopist made a false positive diagnosis and reported tumor present in 3 cases with findings suspicious of tumor reported in 3 others.

Papanicolaou smears were prepared in 48 of the 100 cases. In one of the cases the smears were prepared only from sputum, in 3 from both sputum and bronchial aspiration or washings, and in 44 cases from bronchial aspiration or bronchial washings only.

In 8 cases, the bronchial smears were reported as positive, and in all 8 cases intrathoracic tumors were present. The slides from 2 cases were considered inadequate for diagnosis. In 38 others, all smears were reported as negative, although in 27 of these 38 cases a final histologic diagnosis of intrathoracic malignancy was made.

TABLE VI. CORRELATION OF BRONCHIAL CYTOLOGIC STUDIES IN 45 CASES WITH PATHOLOGIC DIAGNOSES ON SCALENE NODES

PATHOLOGIC DIAGNOSES	CYTOLOGIC DIAGNOSES	
	NEGATIVE	TUMOR
Negative	27*	4
Tumor	10	4

*The final clinical diagnosis was tumor in 16, tuberculosis in 3, and miscellaneous in 8 cases.

Cytologic material previously reported as negative for tumor cells was available for review in 32 of these 38 cases. In the other 6 cases the smears were done at another hospital or for some other reason were not available at this time. The available smears, from 2 to 6 in number from each case, were reviewed and divided into the following 4 categories according to the quality and quantity of the cells present and the diagnosis made on those cells: (1) positive for tumor cells, 3 cases; (2) suspicious for tumor cells, but with cells too few or morphologic detail too poor to warrant a diagnosis of cancer, 10 cases; (3) no tumor cells present in a smear containing sufficient cells of good morphologic quality, 10 cases; (4) cells quantitatively or qualitatively too poor to permit a definitive diagnosis, 9 cases.

Excluding the last mentioned group of 9 cases, those in which the smears were either qualitatively or quantitatively insufficient for diagnosis, there were 23 cases in which all smears were originally called negative. Seventeen of these patients had intrathoracic neoplasms, while 6 had no neoplastic disease. On review, smears from 2 of these 17 cases were called positive, 6 cases were called suspicious, and 9 cases were called negative. In the 6 nontumor cases, the review cytologic diagnosis was positive in 1, suspicious in 4, and negative in only 1.

As noted above, 27 of the 38 cases in which smears were originally diagnosed as negative had a final histologic diagnosis of intrathoracic neoplasm. In 10 of these 27 cases, a positive diagnosis was made on the scalene node biopsy specimens.

The diagnosis of sarcoidosis was made on lymph nodes from 11 per cent of the 100 cases, a figure corresponding with that reported by others. In no case in this series did sarcoid coexist with tumor. Tuberculosis was found in one case coexisting with bronchogenic carcinoma. In this case, the specimens from bilateral scalene node biopsy were diagnosed as tuberculosis, while the diagnosis of cancer was established by bronchoscopy.

DISCUSSION

The frequency with which positive diagnoses on scalene nodes were made in this series in cases of intrathoracic neoplasm is somewhat higher than that

reported by others, despite the fact that this series included all cases in which tissue was sent to the laboratory, regardless of the number of lymph nodes identified. In a few cases considered as negative, no nodes were identified in the submitted pad of fibro-fatty tissue.

The diagnostic accuracy of scalene node biopsy in different series varies from the 20 per cent reported by Wilson, Laforet, and Strieder[8] to the 48 per cent reported by Horwitz and Findlay.[7] A meaningful comparison of the number or percentage of positive diagnoses in the different reported series, however, is difficult unless criteria are reported for the selection of cases for biopsy in each series. Thus, where scalene lymph node biopsy is performed in cases of clinically obvious neoplastic disease, as sometimes occurs in this hospital in order to obtain histologic proof of the malignant nature and inoperability of the lesion, one would expect the percentage of positive diagnoses of neoplasm in such biopsy specimens to be quite high. When, on the other hand, the scalene node biopsy is performed more or less routinely for diagnostic purposes in cases of intrathoracic disease of all types one would expect to find cancer in the pathologic specimen relatively infrequently. In the series reported here, as noted under Material and Methods, the scalene node biopsies were done when an intrathoracic neoplasm was suspected. Some of these biopsies were done with the thought that thoracotomy could be forestalled if a positive diagnosis of metastatic disease could be obtained by this relatively simple, although by no means completely inocuous, procedure.

The study of Horwitz and Findlay demonstrates another factor that will influence the number of positive diagnoses in patients suspected of having intrathoracic cancer, namely the palpability of the supraclavicular nodes. Positive biopsies were obtained in 14 of 15 cases in which nodes were palpable, while only 10 biopsy specimens contained tumor out of 29 cases in which nodes *were not* palpable.[7]

It will be noted here that although bronchoscopy was performed in 63 cases, cytologic preparations of bronchial secretions or washings were made in only 47 of them. In most of the 16 cases in which smears were not made, the diagnosis of neoplasm was considered fairly obvious at the time of bronchoscopy and cytologic studies were not thought necessary to establish a diagnosis. The effect of this selection by the bronchoscopist, of course, was to reduce the number of cases studied cytologically in which tumor extended to, or into, the lumen of the bronchial tree and in which, presumably, exfoliated tumor cells might have been fairly numerous.

The frequency of positive cytologic diagnoses reported by others in cases of bronchogenic cancer range from the 44 per cent reported by Shabart[13] to the 95 per cent reported by Foot[14] with the average diagnostic accuracy between 70 and 85 per cent.

The reasons for the relatively low number of positive cytologic diagnoses, 8 of 46 cases (27 per cent), seemed to number 4. First, cells were either not exfoliated into the bronchial tree or exfoliated cells were prevented by bronchial obstruction from reaching the collection point. Second, that the techniques employed in obtaining exfoliated cells from bronchial lumens were unsatisfactory.

Third, that the techniques of preparing the smears did not furnish adequate material, either qualitatively or quantitatively, for microscopic examination. Fourth, that cytologic preparations were read as negative when, in fact, tumor cells were present.

With regard to the first of these possibilities, we feel that the tumors in this series were in all likelihood similar in location and size to those in other reported series in which the accuracy of cytologic diagnosis was much higher, ranging from 44 to 95 per cent or better in patients with bronchogenic cancer.[6, 10-14] Thus, the location or type of tumor is not considered to be the major source of diagnostic difficulty. The second possibility also seemed unlikely as the major reason for the discrepancy between cytologic and tissue diagnoses in this series. In general, material was aspirated for cytologic study whenever it was possible to obtain a sufficient quantity. If it was impossible to do so, a small amount of saline was introduced into the bronchus and the washings were collected. These methods of obtaining material have varied but little in the past 7 years and are essentially the same as those used in other hospitals.

Review of the third possible source of diagnostic difficulty, the techniques of handling the material once the specimens were obtained, has furnished the best explanation for the relatively large number of "false negative" cytologic diagnoses. It has been the assumption of both the clinician obtaining the material for cytologic examination and the man actually looking at the microscopic slide that the intervening steps of processing the specimen have been performed in the way best calculated to furnish a positive diagnosis if tumor cells have been exfoliated into a patent bronchus. In actual fact, there has been a wide variation in the procedures followed during the 7-year period covered by this report. This variation in procedure has coincided with a moderate turnover in personnel at all levels in the clinical and laboratory services.

During a part of this time smears were prepared by the bronchoscopist who, after aspirating the fluid content of a particular bronchus, would spread some of the material on a glass slide and then immerse the slide in ether-alcohol mixture. Even in this relatively straightforward procedure the variable noted above was occasionally introduced, namely the use of a small quantity of saline to "wash" a visible lesion. When this was done, a random sample of the washings were smeared onto a glass slide. At other times all liquid material obtained by bronchial aspiration, whether strictly bronchial secretion or supplemental washings, was sent to the laboratory for preparation of the smears. In the course of this latter procedure there again was a chance for one or more variables to affect the diagnostic accuracy of the method. Although the best cytologic practice demands prompt fixation of the material, there was often a time lag from one to several hours between the time the material was obtained and the time it was spread on a slide and fixed. This time interval depended on whether the material was sent directly to the laboratory or was left for the routine pickup of operative specimens from the operating room.

Another variable was in the selection of the material to be smeared on the slide. Usually the material was centrifuged before smearing, but in some instances a random sample of the uncentrifuged material would be smeared by

laboratory personnel. Then too, the number of slides prepared, whether by the bronchoscopist or in the laboratory, varied from 1 to 4, with 2 the usual number. The responsibility for making this preparation was often not given to any one person and at times appropriate instructions for processing were not given to the laboratory personnel. As a consequence, there were wide differences in both the quality and the quantity of cells seen in the cytologic preparations during this 7-year period.

It is interesting to note that, despite the number of variables actually operating in the collection and processing of material from the bronchial tree, when questioned about methods most of the persons concerned with this procedure believed that fairly standardized techniques had been employed. Thus, the bronchoscopist, if he did not prepare the smear directly in the operating room, assumed that the aspirated material or the bronchial washings were being submitted to the laboratory for cytologic examination within minutes after the material was obtained. Once the aspirated material was properly tagged and the appropriate forms completed, the operating room nurse assumed that somehow the material was promptly transported to the laboratory. In actual fact, when this study was made the time lag between the operating room and the laboratory ranged from minutes to several hours. At the same time, however, laboratory personnel receiving the aspirated material assumed that the material had been brought to the laboratory immediately after being obtained.

In considering the fourth possible reason for the small number of positive smears, it is noted that the pathologist in reading the slides appears to have concerned himself primarily with the recognition of any tumor cells present. Thus, if there were no recognizable tumor cells he would report the smear as negative, despite the fact that most of the epithelial cells present may have been poorly preserved or inadequate for a definitive diagnosis. Comment may have been made on the preservation of cells but only rarely was the preparation reported as inadequate, despite the fact that 12 of the cases of intrathoracic neoplasm reviewed during this study were considered to have smears inadequate for a definitive diagnosis. If these 12 cases were eliminated from the series, then the diagnostic accuracy based on the original cytologic diagnoses would be raised from 8 out of 35 (23 per cent) to 8 out of 23 (34 per cent).

The primary reason for the disparity between the results of this cytologic study and those reported by others, then, would appear to be deficiencies in the techniques of processing the smears. Although, perhaps the best smears of bronchial aspiration or washings from all points of view are those prepared after centrifugation of freshly obtained material, the time which elapses between the bronchial aspiration and fixation is probably of greater importance than the centrifugation. When there is any possibility that more than half an hour will elapse between obtaining the specimen from the patient and fixing the material on a slide it would seem far better to have the bronchoscopist smear the aspirated material directly on slides and immerse them immediately in fixative. There may be fewer cells present in the smear than if the material had been centrifuged but, on the other hand, that material which is present will be well preserved.

If it is felt that more satisfactory cytologic preparations can be made after centrifugation of the specimen, then it would seem to be essential that a definite routine be established and that the responsibility for performing the necessary procedures be specifically assigned to one person in either the surgical or the laboratory service. Without such a designated routine, supervised by one individual, variation in procedures seems quite likely to occur *without the knowledge of either the collector of the specimen or the interpreter of the final preparation.*

Despite the rather low diagnostic accuracy of the smear in this study, 23 per cent in 35 cases of intrathoracic neoplasm, it is encouraging to note that there were only 3 cases of cancer in which negative results were obtained by bronchoscopy, cytologic studies, and lymph node biopsies. It has become almost standard procedure to perform all 3 studies at one sitting in suspected cases of intrathoracic neoplasm.

SUMMARY

One hundred consecutive cases from the years 1951 to 1958 were reviewed in which scalene node biopsy was performed as an aid in the diagnosis of intrathoracic disease. A diagnosis of tumor was made by the bronchoscopist in 70 per cent of the cases. Scalene node biopsy specimens were positive for tumor in 60 per cent of the cases when intrathoracic tumor was present. Cytologic preparations were usually made in cases which were diagnostic problems, and were not made in several cases with clinically obvious neoplastic disease. These smears contained tumor cells in only 23 per cent of the cancer cases. The relatively low diagnostic accuracy of the cytologic studies is attributed primarily to deficiencies in the techniques used in preparing the smears. On review of smears originally called negative, approximately 30 per cent were found to be insufficient for definitive diagnosis. If these inadequate smears are not considered, the diagnostic accuracy of the cytologic material becomes 34 per cent in cases of intrathoracic tumor. Each of these 3 diagnostic methods, bronchoscopy, scalene node biopsy, and cytologic study, is felt to have a definite place in the diagnostic armamentarium and each would appear to be most useful as a complemental technique rather as a replacement for the other two.

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MONILIAL EMPYEMA TREATED SUCCESSFULLY WITH INTRAPLEURAL INSTILLATIONS OF AMPHOTERICIN B

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EMPYEMA due to *Candida albicans* is an uncommon occurrence according to the literature, and effective agents for the treatment of this complication have been few. Amphotericin B recently was found to be a useful antibiotic against monilia,[1, 2, 3] and its antiyeast activity in man was reported by Childs,[4] and Halde and co-workers.[5] The fate of amphotericin B following oral, intramuscular, and intravenous administration has been described by Louria,[6] and Taylor and co-workers.[7]

The following case report concerns a patient who developed an empyema due to *Candida albicans* which was successfully treated by intrapleural instillations of amphotericin B.

CASE REPORT

A 54-year-old white man was admitted to the Francis Delafield Hospital, New York City, with the chief complaint of anterior chest pain and cough for 7 weeks. On physical examination, wheezes and rhonchi were heard over the right lower chest posteriorly, and there was clubbing of the fingers.

Significant laboratory findings showed a sedimentation rate of 60 mm. per hour, sputum smears were negative for *Mycobacterium tuberculosis* and several sputum cultures yielded only *Bacillus proteus.* Chest films revealed a cavitary mass lesion in the right lower lobe. An endoscopic biopsy from the lateral basal segmental bronchus of the right lower lobe was positive for carcinoma.

Following adequate preparation, a right pneumonectomy was performed. Examination of the specimen showed the mass in the right lower lobe to consist of undifferentiated carcinoma, and there were metastases to the tracheobronchial lymph nodes.

The patient did well after surgery until the fourteenth postoperative day, when he had a shaking chill and fever. Empyema of the right chest was diagnosed, and *Staphylococcus aureus* coagulase positive was cultured from the pleural fluid. The organism was sensitive only to chloramphenicol, novobiocin, and bacitracin. Systemic and local antibiotics were given as noted in Fig. 1, and repeated thoracenteses were performed. It became evident that the right chest could not be evacuated by needle aspiration. Two closed thoracotomies were then performed which also did not give the desired result. On the thirty-second postoperative day, an open thoracotomy was performed with the removal of all residual fluid and fibrin.

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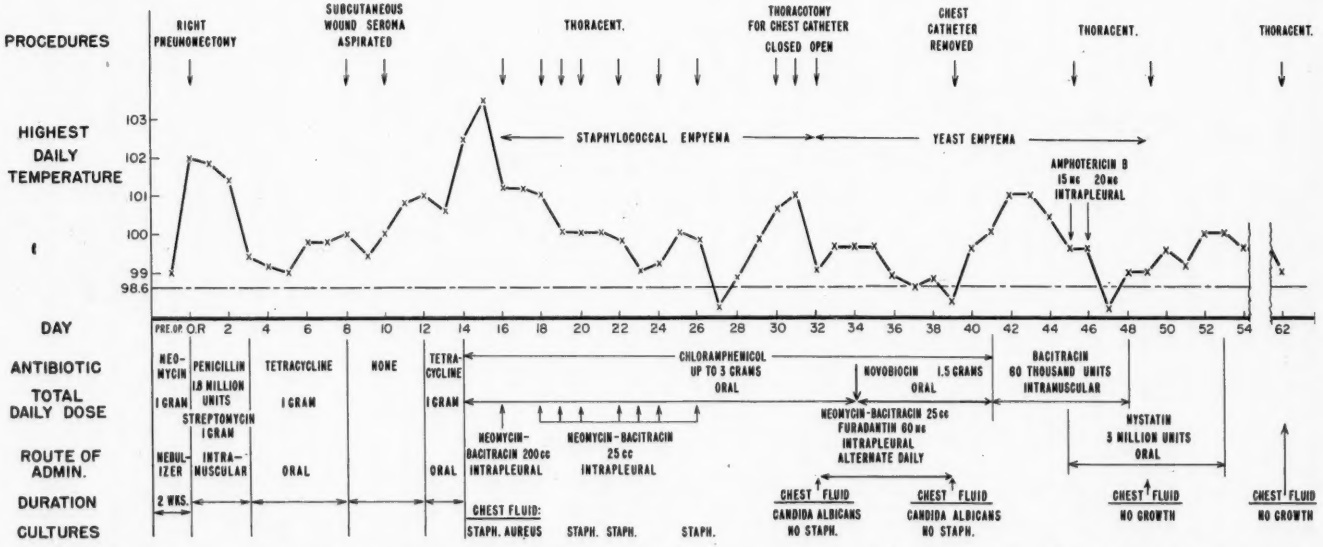

Fig. 1.—Summary of clinical course and treatment given. The neomycin-bacitracin solution contained 500 U./c.c. of bacitracin and 5 mg./c.c. of neomycin.

The wound was closed after a large drainage tube was inserted through a nearby interspace. Subsequent cultures were negative for *Staph. aureus*, but *C. albicans* became evident for the first time. Stool cultures also grew out this organism.

Following several days of improvement, he again developed fever. Nystatin was given by mouth to eliminate monilia from the gastrointestinal tract which was the only other known reservoir of this organism. On the forty-sixth postoperative day, 15 mg. of amphotericin B* was instilled into the pleural cavity. On the next day this treatment was repeated with 20 mg. of the drug. Following this, the patient had nausea, vomiting, malaise, pain in the right lower chest, but no fever. Fluid reaccumulated in the pleural space, but no organisms could be cultured from it after the amphotericin therapy. He was discharged from the hospital without evidence of infection.

Other significant laboratory data showed only *B. proteus* in the sputum during the entire hospital stay. Blood cultures failed to grow *C. albicans*. The patient was observed for 6 months following his discharge from the hospital, and repeated cultures were taken during this period. The blood, pleural fluid, and urine have remained sterile, and *C. albicans* was not cultured from the sputum or stool.

COMMENT

In retrospect, it would seem that *C. albicans* was introduced into the pleural cavity during one of the needle aspirations or tube insertions. When this pleural contamination was first discovered, we were not certain of its pathogenic significance. The possibility of persistent although uncultured staphylococcal infection was also entertained. Because of recurrent fever and re-collection of pleural fluid, it was decided to treat a possible bacterial empyema and a known yeast empyema. Intramuscular bacitracin was given to control the former possibility and amphotericin B was selected to treat the monilial infection.

Although intravenous amphotericin was recommended for systemic monilial infection,[6] the intrapleural route seemed to be a more direct method of treatment. Following the first intrapleural instillation, there were mild malaise and nausea. After the second injection, the patient developed severe nausea, vomiting, and chest pain. Amphotericin was discontinued, and these symptoms quickly subsided. Since the untoward reactions were so closely related to the amphotericin therapy, the concomitant nystatin and bacitracin were discounted as complicating agents. The patient's symptoms disappeared before these two agents were withdrawn. The systemic reaction indicated that there was absorption of amphotericin B from the pleural cavity although blood levels of this drug were not measured. Pleural sterilization of all organisms ultimately was achieved.

The delay of open thoracotomy on this patient may be criticized. Because the patient had known residual carcinoma in the mediastinum, it was hoped that the empyema could be cured by more conservative means. The pleural fluid was thin and turbid at all times. From this experience, it is recommended that all pleural fluid and material contaminated with *C. albicans* be evacuated from the chest followed by the instillation of amphotericin B. The use of a thoracotomy tube may be necessary. Whether a closed or open thoracotomy is used depends on the efficiency of pleural evacuation with the closed method. The removal of

*Amphotericin B (Fungizone) was supplied by the Squibb Institute, New Brunswick, N. J.

pleural contents must be performed under direct vision when other methods fail. Following intrapleural administration of amphotericin B, the patient must be followed closely for untoward systemic reaction.

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IDIOPATHIC MUSCULAR HYPERTROPHY OF THE ESOPHAGUS

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IDIOPATHIC circular muscle hypertrophy of the esophagus, first described by Baillie in 1799,[1] was reviewed in 1949 by Salfelder[2] who discovered 35 autopsy cases of "esophageal hypertrophy," 4 demonstrating "idiopathic hypertrophy." Abbo and Giampalmo[3] identified 6 postmortem instances of marked degrees (0.7 to 1.1 cm.) of circular muscular hypertrophy. Sloper[4] presented 7 additional cases in 1954. Biocca[4] reviewed the literature in 1956, found 42 cases, and added 2 of his own in which surgery was performed. Sweet[5] has encountered 2 patients, Burford,[6] one, and Womack,[7] 2 patients. The following report brings the available recorded cases to 50, in 9 of which there was some form of surgical intervention.

CASE REPORT

A 51-year-old, white, married man was admitted to the hospital on Oct. 30, 1957, complaining of "stomach trouble." Twenty years prior to admission he had had substernal pain associated with nausea and vomiting. Conservative medical therapy relieved him. Subsequently he had had occasional, mild, epigastric distress, and rare, nocturnal nausea and vomiting. Three weeks prior to admission, continuous substernal pain with nausea and vomiting recurred. This distress was not related to position, meals, or activity. Hematemesis was absent. An esophagogram done elsewhere revealed an "esophageal abnormality." Dysphagia occurred for the first time 2 weeks prior to admission.

The past history revealed diphtheria in early infancy and recent mild prostatitis treated by massage.

Physical examination was normal except for a compensated anodontia and a mild prostatic enlargement. Blood pressure was 105 systolic, 60 diastolic; pulse rate 80; respirations 20; temperature 98.0° F.; weight 135 pounds.

Laboratory studies: the urine had a specific gravity of 1.023, acid, a trace of albumin, and 15 to 20 WBC's per HPF. The hemoglobin was 14.7 grams per cent and the total white count was 14,000 per milliliter, with 29 polymorphonuclears, 42 eosinophils, 1 basophil, and 28 lymphocytes. The blood urea nitrogen was 18 mg. per cent and the VDRL was nonreactive.

The chest films were normal. An esophagogram demonstrated curling of the esophagus with a delay in emptying in the distal 6 cm. The mucosal pattern was normal (Fig. 1, *A*). Esophagoscopy showed hypertrophied mucosal rugae from the 30 cm. level to the diaphragmatic pinchcock.

On Nov. 4, 1957, a left thoracotomy and mediastinal dissection exposed a firm, thickened esophagus. A frozen section from the esophageal wall was reported as benign smooth

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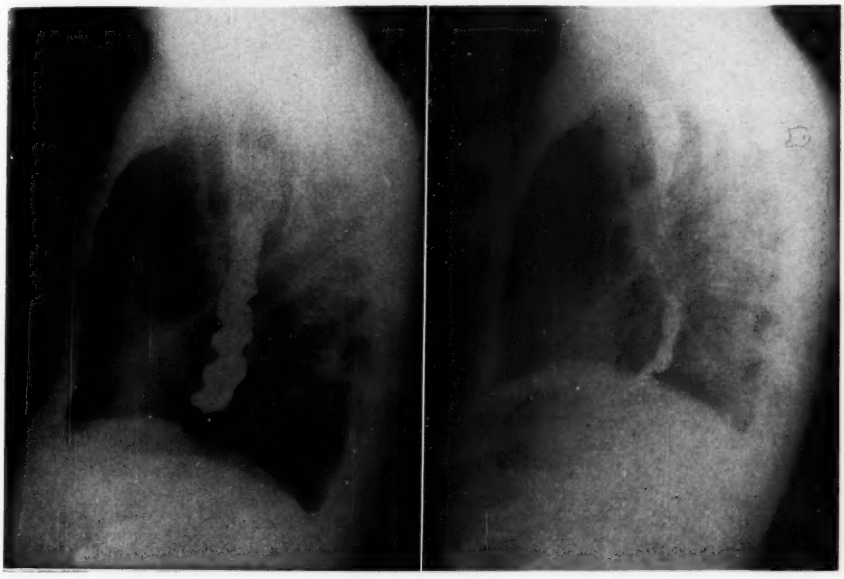
muscle. An extra-submucosal myotomy from the aortic arch to the gastric cardia was performed. As the myotomy was performed, the mucosa and submucosa bulged outward (Fig. 2). Digital exploration of the cardia, via a gastrotomy, revealed no esophageal obstruction. A small sliding hiatal hernia was repaired and a routine closure performed. The thoracotomy tube was removed on the third postoperative day and the Levine tube on the fourth postoperative day. An esophagogram on the eighth postoperative day and on the twelfth postoperative month (Fig. 1, *B*) showed mild esophageal dilatation with slight cardial delay of the barium. The patient was discharged without sequelae on the ninth postoperative day. Complete blood counts 3 and 12 months following surgery were normal.

Microscopic examination of the circular muscle demonstrated smooth muscle hypertrophy without loss of muscular orientation. An eosinophilic infiltration was present in the perivascular and perineural tissue spaces with questionable lymphangiectasis (Fig. 3).



A. *B.*

Fig. 1.—*A*, Preoperative esophagogram. *B*, Postoperative esophagogram.

ETIOLOGY

Embryologically, the circular muscle layer and myenteric plexus of Auerbach appear at 7 weeks (17 mm. embryo) and the outer, longitudinal layer appears at 12 weeks (56 mm. embryo).[8] There have been no reported cases in which Auerbach's plexus has been deficient.

Guthrie's patient,[9] aged 11 years, is the youngest reported to date. Vargas and associates[10] reported a 7-week-old infant with annular hypertrophy of the cardia treated by the Heller procedure. However, the average age of these patients is 60 years and tends to rule out a congenital etiology. The lack of fibrosis and inflammatory exudation in the available microscopic descriptions rules out an inflammatory process.

Fig. 2.—Bulging of the mucosa and submucosa at the time of surgical myotomy.

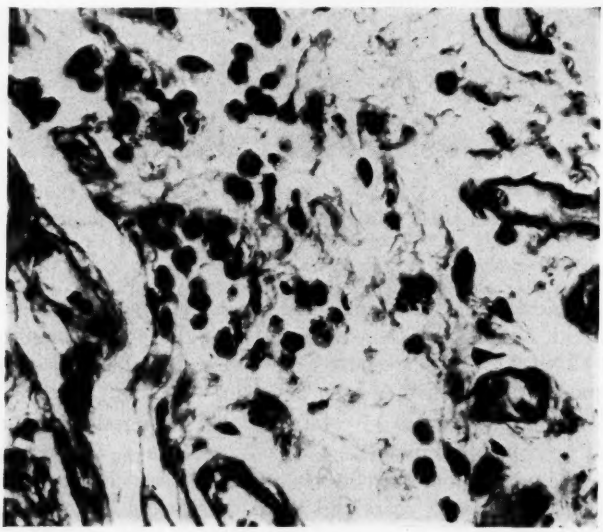


Fig. 3.—Microphotograph which demonstrates the perivascular and perilymphatic eosinophilic infiltration. (×480.)

The role of sympathetic-parasympathetic imbalance is difficult to assess. Allison (cited by Sloper[1]) performed a cervical vagotomy without benefit. Sympathectomy has not been performed. The frequently mentioned perineural and perivascular infiltration of eosinophils cannot be presently correlated with any known neuromuscular imbalance.

The frequent occurrences of myocardial hypertrophy in these patients has suggested a humoral concept.[1, 3, 4] Many of these patients are in the older age groups and have associated arteriosclerotic vascular lesions easily justifying left ventricular hypertrophy. Abbo and Giampalmo[3] noted an association of pyloric hypertrophy in 7 of their 26 cases, and Sloper[1] found one in his 7 cases. The incidence of malignancy in other body systems is high in these patients' protocols; Abbo and Giampalmo[3] found six malignancies in 26 cases, and Sloper[1] found five malignancies in 7 cases.

The late onset of symptoms indicates that it is an acquired lesion, possibly based on an obscure allergic basis.

DIAGNOSIS

Difficulty in swallowing, substernal discomfort or pain, and a history of remissions and exacerbations constitute a triad of symptoms. These people learn to chew their food well before swallowing. Nausea and vomiting (not self-induced) are uncommon. Patients have generally learned to live with their disease without excess distress. The onset of mild to moderate substernal pain most commonly brings them to their doctor. Weight loss occurs late, if at all.

The barium swallow demonstrates an intact esophageal mucosa with poor peristaltic activity (although Biocca[4] reported a patient having marked activity). The barium column may hesitate at the cardia, but esophageal retention is usually not present. The esophageal lumen is not commonly stenosed. Curling may be present. Esophagoscopy may reveal hypertrophy of the mucosal folds or mucosal atrophy, impingement of the esophageal lumen (rare), and lack of bleeding, other than that usually encountered during esophagoscopy.

PATHOLOGY

Eighty-five per cent of reported patients are male, averaging 60 years of age. The hypertrophy is confined to the circular, smooth muscle layer of the esophagus. The outer, longitudinal layer is not involved. Rare involvement of the muscularis-mucosa has been reported.[3] Submucosal leiomatosis not extending into the muscularis and presenting a granular appearance has been reported.[1, 3] Perivascular and perineural lymphocytic and, particularly, eosinophilic infiltrations have been frequently reported.[1, 3, 4] Diffuse esophageal muscular hypertrophy and pyloric and small intestinal hypertrophy have occurred simultaneously.[9]

The esophageal involvement, generally, extends from the aortic arch to the esophagogastric junction, where circular muscular hypertrophy abruptly ceases. The esophagus is firm and rubbery and the surrounding tissues are not inflamed or fibrosed.

TREATMENT

Asymptomatic patients require no therapy. Dilatations are probably of little benefit. Patients with refractory symptoms should undergo surgery. Vagotomy, as demonstrated by Allison,[1] probably has no place in therapy. Sympathectomy has not been attempted and is probably not indicated. Sweet[5] and Womack[7] performed esophagectomy on their first patients and an extra-submucosal myotomy on their second, with successful outcomes.

Allison[1] performed esophageal resection after an unsuccessful cervical vagotomy. Burford[6] and Biocca[4] performed extra-submucosal myotomies with successful results. An extra-submucosal esophageal myotomy from the aortic arch to the diaphragmatic hiatus was done with an excellent result in the patient reported here. This seems to be the surgical treatment of choice, once a malignancy has been ruled out.

SUMMARY

A 51-year-old white man, complaining of dysphagia, substernal pain, nausea and vomiting, was found to have curling of the esophagus by esophagogram, and markedly hypertrophied mucosal rugae by esophagoscopy. On a diagnosis of muscular hypertrophy, an extra-submucosal myotomy was performed with complete relief of symptoms.

Fifty similar patients have been reported. Vagotomy has been tried and found ineffective. The most effective treatment is myotomy of the esophageal muscle down to the submucosal layer, usually extending from the aortic arch to the cardia.

We wish to express our appreciation to Giuseppe Toglia, M.D., for his aid in translation of the articles from Italian medical journals.

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TRANSTHORACIC TRACHEOSTOMY

An Experimental Study

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THE STIMULUS for the present work arose from the observation of a group of 11 patients with compression of the thoracic portion of the trachea, in 3 of which a cervical tracheotomy was performed with poor or no results. In 4 of these patients, the obstruction was secondary to metastatic bronchogenic carcinoma, in 2, it was due to aneurysm of the ascending portion of the aorta, and in one each of 5 to pleural mesothelioma, primary carcinoma of the trachea, Pancoast tumor, scleroma, and adenoma of the trachea. All these cases were inoperable either because of the advanced stage of the disease or because of its situation in the chest, and all produced severe obstruction to the free flow of air. It was thought that the only true palliation for this type of patient was an air shunt beyond the site of obstruction; therefore, the present study was undertaken in the hope that the results could be used in human beings.

The review of the literature revealed that for more than 40 years there have been repeated attempts to deal with endothoracic obstruction of the trachea. Thus, in 1907, Gluck[1] attempted a posterior bronchotomy but was unsuccessful. Later it was conceived that the solution was in the formation of a posterior pulmonary or bronchial fistula and the following schemes were tried: (a) retrograde respiration through an incision of sufficient size to reach a large bronchiole or a bronchus, (b) resection of a pulmonary lobe or a portion thereof so as to obtain the same retrograde respiration, and (c) transpleural bronchial fistula with suture of the margins of the skin to the walls of the open bronchus. Küttner,[2] in 1908, operated on a patient with compression of the trachea produced by an aortic aneurysm; this author resected the upper lobe and fixed the open bronchus to the skin but the patient died a few days later. In 1922, Rethi-Pest[3] published a report of a case of a pulmonary fistula performed in two operations in a patient with aortic aneurysm who survived 14 months and 12 days with an adequate respiratory exchange through the fistula. In the same year, Kirasek[4] attempted a posterior bronchotomy following Gluck's technique but unfortunately the patient died the next day. With the exception of Rethi-Pest's case, all other attempts were unsuccessful.

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Other means to relieve the obstruction of the trachea were suggested by Guleke.[5] Following the decompressive mediastinotomy, described in 1897 by Milton,[6] this same procedure has also been supported more recently by Abbott[7] who has emphasized the fact that several weeks must elapse after the procedure before the patient can appreciate the beneficial results. Sloan and Cowley[8] published, in 1951, a report of a case of aortic aneurysm with severe compression of the trachea in which they performed a posterior mediastinal tracheotomy by means of a rubber tube; the patient died 4 months later with rupture of the aneurysm but throughout the postoperative period the tracheotomy functioned adequately. The authors stress the necessity of constant aspiration of the artificial airway, as well as intense treatment with antibiotics since secretions are abundant and easily become infected. In 1942, Watson[9] reported a case of primary carcinoma of the trachea with resection of the involved segment and anastomosis of the cephalic end to a skin tube with an opening practiced beforehand in the sternum. Kleitsch[10] performed a tracheotomy in a case of recurrent carcinoma of the larynx and opened the trachea to the skin by means of a polyethylene tube at the level of the sternum; this author insists on the convenience of the anterior access because the patient can look after the stoma and sleep in a dorsal position. A similar case was reported by Minor[11] who anastomosed the trachea to the sternum; both authors emphasized the importance of keeping the new respiratory tract patent by means of repeated aspirations and of the uninterrupted use of antibiotics.

We have also attempted the transthoracic tracheotomy with a rubber tube after Sloan and Cowley[8] in a case of low tracheal obstruction but the patient was lost in the operating room because of unsurmountable technical problems.

The only published experimental work is the one by Minkin[12] who, in 1925, performed transpleural bronchotomy in 26 dogs; his work contains detailed descriptions of the surgical access and technique. The operation consists of a transverse bronchotomy in situ after an X incision and removal of the fourth and fifth ribs; the bronchial opening is anastomosed to an infundibulum formed with the skin. The longest survival was 3 days and the cause of death was always empyema.

EXPERIMENTAL DATA

Forty-six dogs, weighing between 15 and 20 Kg., were operated upon, anastomosing the thoracic trachea to the lateral aspect of the right side of the chest. In 32 of these animals, a complete autopsy was performed, histologic sections were examined in 25, and pre- and postmorten bacteriologic studies were carried out in 18.

The animals were anesthesized by means of an endotracheal tube and an ether-oxygen mixture; induction was carried out with intravenous "Kemital." In all cases, a right thoracotomy with removal of a rib was performed and, during the operation, blood and fluids were administered according to needs. Antibiotics were used postoperatively in all animals.

Variations in surgical technique permit separation of our animals in the following three groups: Group 1—complete endothoracic tracheostomy, 23 dogs; Group 2—partial endothoracic tracheostomy with a polyethylene tube, 18 dogs; and Group 3—partial endothoracic tracheostomy with a polyethylene tube covered by skin, 5 dogs.

RESULTS

Group 1. Complete Endothoracic Tracheostomy.—

After opening the thorax and resecting the fifth rib in the usual manner, the trachea is dissected in its endothoracic portion as high as possible, fixed by means of two separate sutures in the cartilaginous portion, and an opening is

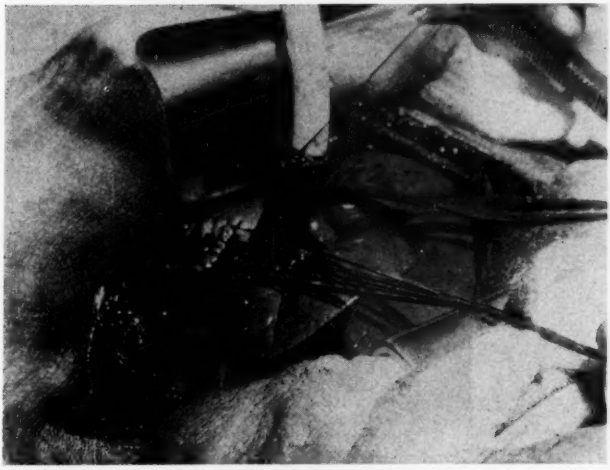

Fig. 1.—Complete tracheostomy. Observe the anesthetic tube introduced in the lower portion of the trachea and the suture of the upper half of the trachea.

made in the membranous portion immediately beneath the two sutures. The upper end is closed with separate sutures and simultaneously the lower end is connected with the anesthetic tube in order to continue the pulmonary insufflation (Fig. 1). The azygos vein is sectioned in order to permit a greater mobility to the pulmonary hilus.

The free end of the lower portion of the trachea is fixed to the wall of the thorax by suturing it to each one of the different planes in order to ensure a permanent position in the parietal course (Fig. 2). Twenty-three dogs were operated upon using the previous technique and they all died in periods ranging from 7 hours (Dog 30) to 14 days (Dog 29). Autopsies were performed in 18, histologic study of lungs and trachea in 14, and bacteriologic studies of tracheal and bronchial secretions in 11. In all animals succumbing after 24 hours or less, there were no clinical manifestations of obstruction and death was

attributed to the operation since the respiratory exchange was adequate. In all animals dying after 24 hours of the operation, the predominant clinical picture was progressive dyspnea and tracheobronchitis ending in bronchopneumonia. Autopsy was performed with special interest in the contents of the tracheobronchial tree, the lungs, and the relation of the trachea with the wall of the chest. In the tracheocutaneous juncture, there were inflammatory and infectious changes while in the tracheobronchial tree there was a whole range of changes from slight to purulent tracheitis and intense bronchopneumonia. The

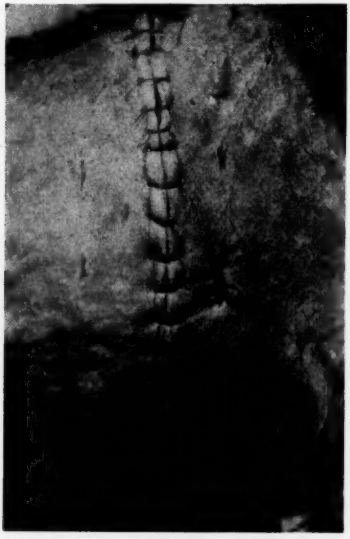

Fig. 2.—Complete tracheostomy. Notice the orifice of the trachea in front of the thoracic wound.

histologic examination confirmed the gross findings and the usual bacteria found were alpha *Streptococcus hemolyticus, Micrococcus pyogenes* var. *albus, Proteus sp., Micrococcus pyogenes* var. *aureus,* and *Klebsiella pneumoniae,* all of which are habitual dwellers in the nasopharynx of the dog. The virulence of these germs was greatly enhanced and they were occasionally associated with *Pseudomonas aeruginosa.* The size of the bacterial proliferation was directly related to the survival of the animals.

Group 2.—Partial Endothoracic Tracheostomy With a Polyethylene Tube.—

The thorax was opened as described and the azygos vein was ligated. The trachea was dissected up to 3 cm. above the carina where two sutures were placed, separated by about 1 cm. Between these sutures a small window was opened in the membranous portion of the trachea and a polyethylene tube, 1.3 cm. in diameter, was introduced in which previously a notch was made to ensure anchorage (Fig. 3). A circular suture was made around the tracheal window

and was firmly tied to the tube; anesthesia was continued through the natural airways and the polyethylene tube was closed with gauze or left open according to the type of experiment to be performed.

This method was used in 18 dogs and in 8 the tube was left open so that the animals breathed both through the natural airways and through the polyethylene tube; all these animals died spontaneously and the gross, histologic, and bacteriologic findings were similar to those described in the previous group. In the remaining 10 dogs, the polyethylene tube, communicating with the trachea, was intermittently opened every day for longer periods with the hope of "conditioning" the animals to breathing through the artificial airway. Dog 32 was reoperated upon 18 days later and the cervical trachea was closed so

Fig. 3.—The polyethylene tube inside the trachea at the point of emergence from the thoracotomy; the muscular layers are sutured.

that the only airway was the polyethylene tube; this animal died 6 days later with the same bronchopneumonic picture. On the other hand, in Dog 33, in which the polyethylene tube was closed most of the time, at the time of sacrifice 60 days after the operation, there were no infectious complications; Dog 38, sacrificed 12 days after the operation and in which the tube was also closed most of the time also showed no infection. In Dog 45, the tube was accidentally removed 8 days after operation but the wound healed satisfactorily and the dog was alive and healthy at the time of last observation (30 days). In the last 4 dogs just described, bronchoscopy was performed which revealed the correct position of the tube and the healing of the wound in Dog 45.

Pathologic examination of the tissues of 7 animals of this group showed that the polyethylene tube was lying in a duct formed by connective tissue with

slight inflammatory reaction, and that, near the trachea, the duct was lined by epidermoid epithelium arising through metaplasia from the tracheal epithelium (Fig. 4).

Group 3.—Partial Endothoracic Tracheostomy With a Polyethylene Tube Covered by Skin.—

In 5 dogs, a portion of skin and superficial muscle, measuring 10 by 6 cm., was removed (Fig. 5) and used as a tube around the polyethylene tube; the skin was sutured around the tracheal opening and again to the margins of the thoracic wound. The polyethylene tube inside the skin tunnel served to avoid

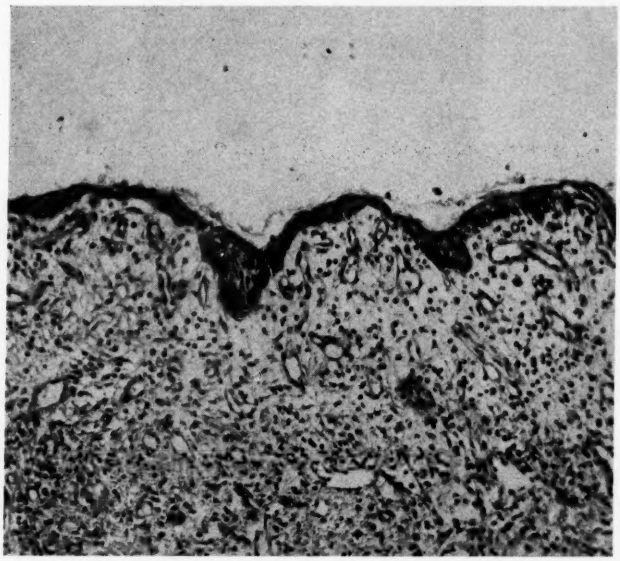

Fig. 4.—Epidermoid metaplasia of the tracheal epithelium near the opening of the tunnel.

collapse (Fig. 6). The animals survived from 1 day to 3 days and the autopsy performed in 4 of them showed infection and separation of the sutures of the skin tunnel to the trachea which adequately explains the presence of empyema and the death of the animals.

DISCUSSION

The surgical technique of experimental transthoracic tracheotomy is relatively simple but care must be observed to leave the new airway as straight as possible in order to avoid accumulation of secretions; the significance of this fact is borne out by the results in the three groups of animals. The anesthesia is also simple and, when complete tracheostomy is performed, it can be continued through the lower segment of the trachea; when tracheostomy is partial,

the administration of the anesthetic is better obtained through the natural airway. At the end of the operation the animal is breathing normally and no râles can be heard.

The animals in the first group died spontaneously with bronchopneumonia in spite of the use of continuous aspiration of the tracheal opening in the chest

Fig. 5.—Preparation of the skin graft in the chest of the dog.

Fig. 6.—Partial tracheostomy. Notice the pedicle skin graft anastomosed to the trachea and sutured as a tunnel containing the polyethylene tube.

and the administration of systemic and local antibiotics. These results illustrate the significant role played by the upper respiratory tract as a defense mechanism against infections, operated by means of secretions, ciliary activity, temperature, humidity, and the cough reflex, suppressed in these animals by anesthesia

and specially by the absence of the larynx in the artificial airway. The bacteria isolated from the nasopharynx in 10 healthy dogs were the same as those usually encountered in the lungs and trachea of the animals operated upon (alpha *Str. hemolyticus, M. pyogenes* var. *albus* [nonhemolytic], *Proteus sp., M. pyogenes* var. *aureus,* and *K. pneumoniae*). The immediate postoperative bronchial washings failed to reveal any bacteria in smears or cultures, thus indicating that the lower respiratory tract is normally aseptic.

In Group 2, a polyethylene tube was used to establish communication between the endothoracic trachea and the environment, and in 8 dogs it was left open so that the animals breathed through both the normal and the artificial airways. Since the fate of these dogs was the same as Group 1 it was decided to close the polyethylene tube in the remaining 7 and this changed the outcome immediately since the animals continued breathing through the normal airways. Additional confirmation of the deleterious influence of a bypass of the upper respiratory tract was obtained in Dog 32, which died with bronchopneumonia when the cervical trachea was closed and it could only breathe through the transthoracic tube.

In a series of animals of Group 2, which died 8 or more days after the surgical procedure (Dogs 32, 33, 37, 38, 41, and 45), it was found that the polyethylene tube was surrounded by a tunnel of connective tissue; in the last animal (Dog 45) the tube was accidentally eliminated and the tunnel closed spontaneously together with the tracheal wound. Bronchoscopy in this dog revealed a healed wound in the trachea. It was then thought that the connective tissue tunnel should be replaced by a pedicle skin autograft in order to ensure its permanent patency and 5 animals were operated upon using the polyethylene tube in order to avoid collapse of the skin tunnel. Unfortunately, the sutures of the skin graft to the trachea were defective and the animals died with empyema without allowing adequate time for observation.

We believe that the present work can be continued by placing the animals in a warm and humid atmosphere, which was not feasible at the time it was carried out, and by placing a wire network around the skin in order to avoid collapse of the tunnel, following Gebauer's method[13]; finally, progressive "conditioning" of the animals to breathing through the artifical airway may improve the results obtained in the present series.

SUMMARY

The observation of a group of patients with obstruction of the endothoracic portion of the trachea in which classical tracheotomy was of no avail suggested an experimental study of transthoracic tracheostomy. Forty-six dogs were operated on according to the three following techniques: Group 1, complete transthoracic tracheostomy; Group 2, partial transthoracic tracheostomy with a polyethylene tube; Group 3, transthoracic tracheostomy with a polyethylene tube covered by skin. The results of these studies and of the pathologic and bacteriologic observations in 32 autopsied animals of the series suggest the following conclusions.

1. Complete or partial, transthoracic experimental tracheostomy is a relatively simple procedure.

2. Results could be improved by replacing the decontaminating functions of the upper respiratory tract which are lost with the procedure.

3. Replacement of such decontaminating functions include an appropriate temperature and humidity of the atmosphere, repeated aspirations instead of the cough reflex, and protection by means of local and systemic antibiotics.

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A TECHNIQUE FOR BICUSPIDIZATION OF THE AORTIC VALVE

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ALTHOUGH there are a dozen or more etiologies for aortic insufficiency, the ultimate problem is similar in most cases. There is a disparity between the area of the aortic orifice and the area of valve leaflet with which this orifice must be covered during diastole. Recently, efforts have been made under direct vision to establish a more favorable orifice/valve leaflet ratio by excision of the noncoronary cusp and conversion of the valve to a bicuspid structure.[1-4, 6, 7] Early results by Bailey with the clinical application of this method appear to warrant a more extensive clinical trial.[1, 2]

Concerning the physiologic consequence of this procedure, several problems remained unsettled. Since bicuspidization of the valve reduces the orifice by more than 50 per cent, the effect of the relative stenosis on the left ventricle is of interest. It is also important to know if it is necessary to excise the leaflet of the noncoronary cusp or if this leaflet can simply be defunctionalized. The present investigation is concerned with these questions and with a description of a simplified method for bicuspidization of the aortic valve.

METHODS

Eleven mongrel dogs (8 to 15 Kg.) were used. The operative procedure and all subsequent tests were performed under sodium pentobarbital anesthesia (25 to 30 mg. per kilogram). Surgery was done under hypothermia (27° to 32° C.), cooling and rewarming being done by immersion in water baths of appropriate temperature. Simultaneous pressures were obtained postoperatively by transcarotid catheters and left ventricular puncture, respectively, and were recorded with an inductance manometer which had a frequency response in excess of 30 cycles per second. Heart sounds and electrocardiogram were recorded with a commercial phonocardiogram.

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DESCRIPTION OF OPERATIVE PROCEDURE

Thoracotomy is performed through the right fourth intercostal space. The azygos vein is ligated and the superior and inferior venae cavae encircled with tapes. The pericardium is opened and a stay suture in the auricular appendage is used to retract the right atrium inferiorly (Fig. 1). The cleavage plane between the right atrium and the noncoronary sinus of Valsalva is developed. Finally, the origin of the right coronary artery is identified (Fig. 1). Both venae cavae are then occluded with Rumel-Belmont tourniquets and the ascending aorta cross-clamped. A longitudinal ascending aortotomy is made and extended proximally through the annulus to the base of the noncoronary cusp (Figs. 1 and 2).

When the lips of the aortotomy are spread and residual blood sucked away, a splendid view of the valve is afforded (Fig. 2). The two points of insertion of the noncoronary leaflet are identified. A needle, swedged with 5-0 silk, is placed through these two points, passing from outside in on one side and inside out on the other side (Fig. 2). Having selected these two points for approximation (Fig. 2), an ellipse of excess aortic and annulus tissue is trimmed away on each side down to within 1 mm. of the previously placed suture (Fig. 3, *B*).

The suture is tied, closing a central point of the aortotomy (Fig. 3, *C*). The aortotomy is closed with a continuous suture, starting proximally and oversewing the guide stitch in the middle (Fig. 3, *D*). Before the last sutures are placed, the venae cavae are released to allow air in the left ventricle to be flushed out, and the aortic clamp is removed.

The period of caval occlusion in this series ranged from 7 to 11 minutes. Ten of the eleven dogs developed ventricular fibrillation, with successful resuscitation in all. In several instances, it was necessary to raise the heart temperature by lavaging the chest with warm saline solution before a good beat could be re-established. Blood transfusions were not given.

RESULTS

Operative Mortality and Morbidity.—There was no mortality at the operating table. One dog died of heart failure (with acute pulmonary edema) 6 days after surgery. The 9 remaining dogs lived for chronic study and their behavior and activity were entirely normal.

Ascultatory Findings.—All chronic dogs were examined for heart murmurs at intervals postoperatively and at least one phonocardiographic recording obtained before they were sacrificed. The findings were similar in every case. There was a diamond-shaped systolic murmur which was heard most distinctly just to the left of the sternum in the second or third interspace (Fig. 4, *B*). In the same location, the second heart sound was invariably accentuated with a snapping tambour quality (Fig. 4, *B*). In no instance was a diastolic murmur present.

Left Ventricular and Aortic Arch Pressures.—The animals were lightly anesthetized with sodium pentobarbital before they were sacrificed, and

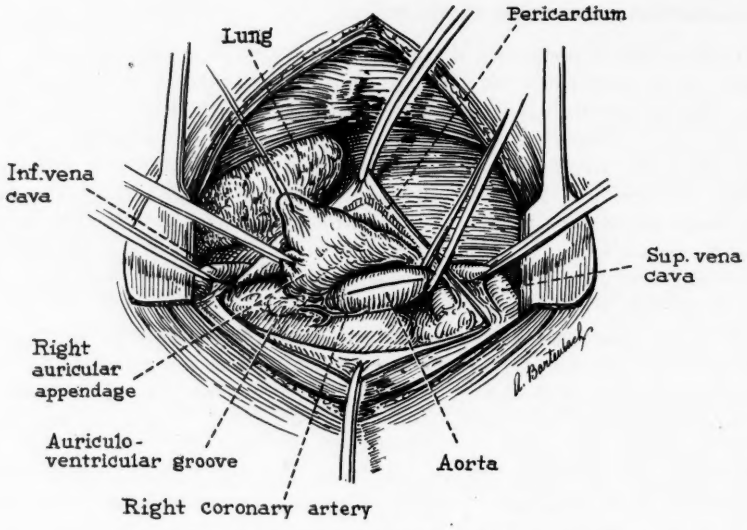


Fig. 1.—View of operative field through right thoracotomy.

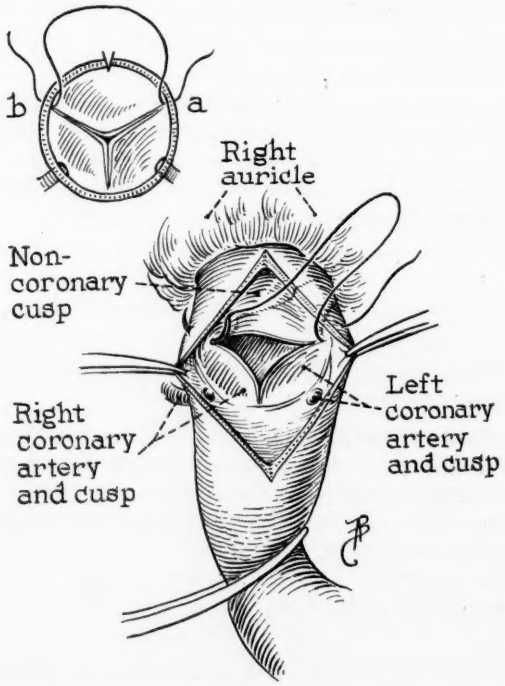


Fig. 2.—Suture at insertions of noncoronary leaflet.

simultaneous pressures obtained from the aortic arch (by retrograde catheterization) and left ventricle (by direct puncture). In no case was a gradient demonstrated between the ventricle and the arch (Fig. 4, *A*). In every case, the aortic pressure complex included a sharp dichrotic notch (Fig. 4, *A*), strengthening the belief that significant regurgitation had not been produced.

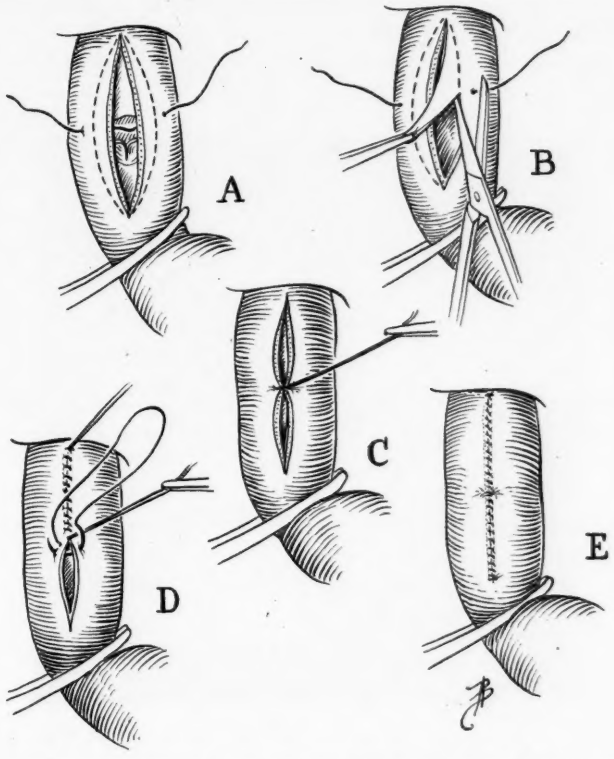
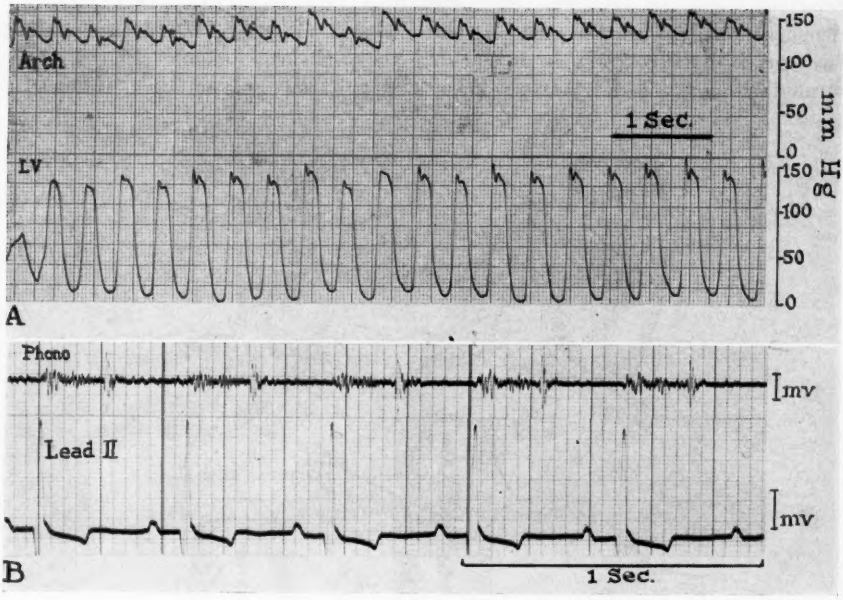


Fig. 3.—Excision of excess aorta, annulus, and cusp. Closure of aortotomy.

Effect of the Operative Procedure on Left Ventricular Weight.—Before sacrificing the animals, accurate body weights were obtained. At autopsy, dissection on the left ventricle was performed by the method of Goodale and Hackel[8] and the dissected left ventricle weighed. The actual weight of the left ventricle was compared with the left ventricular weight which was anticipated on the basis of body weight according to the Goodale-Hackel coefficient. As a control, hearts from 18 dogs sacrificed in various acute experiments were also weighed (Fig. 5).

The left ventricular weights of the normal control dogs are seen on the left in Fig. 5. On the right, expressed in per cent of predicted weight, are depicted the left ventricular weights of the 9 chronic dogs at various times after aortic

A.



B.

Fig. 4.—Pressures, phonocardiogram, and electrocardiogram 3 months postoperatively (Dog 9).

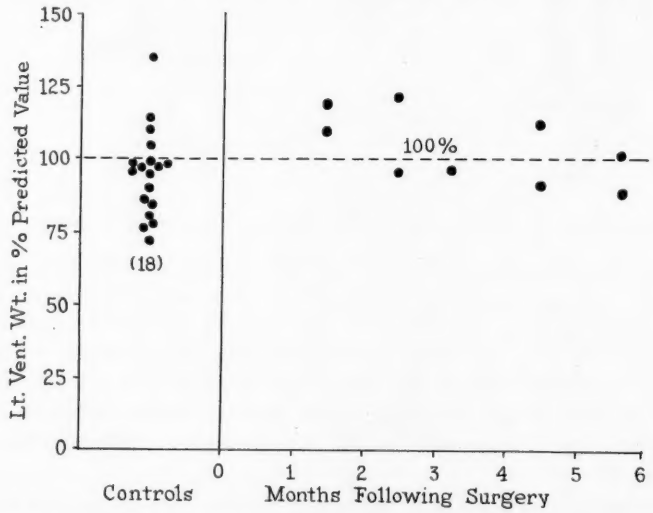


Fig. 5.—Left ventricular weights at autopsy, expressed as per cent predicted value. Control dogs are at left.

valve bicuspidization. It is seen that in 4 cases the weights were slightly less than predicted, in 4 cases slightly greater, and in one case exactly the same. Thus, in the series studied, there is no evidence of hypertrophy up to 6 months postoperatively.

Autopsy Findings.—Two animals died 6 days postoperatively, one as a result of empyema and the other of heart failure. Nine animals were electively sacrificed at 6 weeks to 5½ months postoperatively. The reconstructed valves were examined with care and sections of liver and lung taken for histologic study.

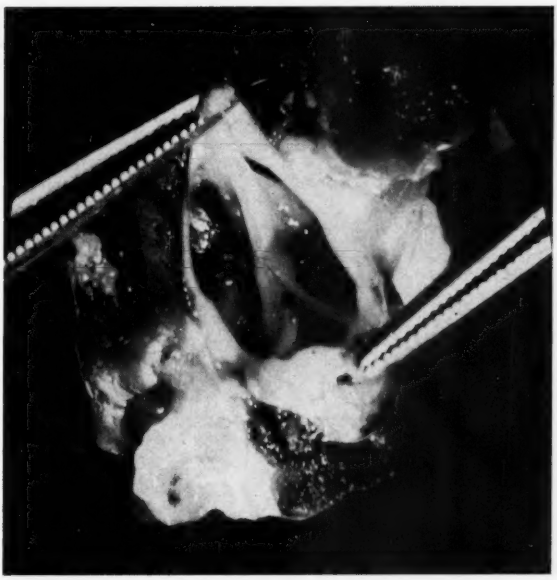


Fig. 6.—Aortic valve in dog (Case 10) in which spread of aortotomy suture line had allowed valve to resume partially tricuspid structure.

In all dogs except one (Case 10), the valves had remained bicuspid. The prolapsed noncoronary cusp was found to be delicate and to be the seat of vegetations in no case. In Case 10, the suture line had spread approximately 2 mm. (Fig. 6). It is interesting that pressures from this animal were entirely normal and that there was no evidence of a diastolic murmur on the phonocardiogram, suggesting that the noncoronary cusp had resumed function and prevented the development of aortic insufficiency.

Excepting the dog which died of pulmonary edema in the immediate postoperative period, there was no gross evidence of heart failure in any animal. One of the 9 animals studied chronically had histologic evidence of chronic passive congestion of the liver and lungs (Table I).

TABLE I

NO.	WEIGHT (KG.)	DURATION	L. VENTRICULAR AORTIC GRADIENT	SYSTOLIC MURMUR	DIASTOLIC MURMUR	AUTOPSY FINDINGS
1	12.7	11 wk.	0	+	0	Valve bicuspid; no gross failure; chronic passive congestion histologically
2	9.0	6 da.				Died of empyema; valve bicuspid
3	9.1	18 wk.	0	+	0	Valve bicuspid; no gross or microscopic evidence of failure
4	10.0	20 wk.	0	+	0	Valve bicuspid; no gross or microscopic evidence of failure
5	9.0	17 wk.	0	+	0	Valve bicuspid; no gross or microscopic evidence of failure
6	10.0	6 da.				Valve bicuspid; gross and histologic pulmonary edema
7	11.0	22 wk.	0	+	0	Valve bicuspid; no gross or microscopic evidence of failure
8	13.2	7 wk.	0	+	0	Valve bicuspid; no gross or histologic evidence of failure
9	15.9	10 wk.	0	+	0	Valve bicuspid; no gross or histologic evidence of failure
10	8.6	6 wk.	0	+	0	Valve had 2 mm. separation suture line and defunctionalized valve covered gap; no gross or histologic evidence of failure
11	10.4	22 wk.	0	+	0	Valve bicuspid; no gross or microscopic evidence of failure

DISCUSSION

The fundamental geometric alteration produced by aortic valve bicuspidization is shown in Fig. 7. The effect on the orifice area of removing one third the circumference is expressed by the formula

$$\frac{Ax}{Ay} = \left(\frac{Cx}{Cy}\right)^2 \text{ or } Ay = \tfrac{4}{9} \text{ the original area}$$

in which Ax = original orifice area = 1; Ay = reconstructed orifice area; Cx = original circumference = 1; and Cy = reconstructed circumference = $\frac{2}{3}$.

Since the leaflet area which is defunctionalized or removed is one third (one leaflet), the end ratio of $\frac{\text{new leaflet area}}{\text{new orifice area}}$ is $\frac{\frac{2}{3}}{\frac{4}{9}}$ or 1.49. Although the calculations indicate that the bicuspid valve now has 1.49 more leaflet area than orifice

area, it is possible that deformation of the leaflet attachments reduces this ratio. It is quite clear, however, from examination of the gross valve, that the bicuspid valve has more leaflet than is necessary to cover the reconstructed orifice. It is probably the excess of leaflet tissue that accounts for the accentuated and tambour second heart sound after surgery.

Previous studies on aortic valve bicuspidization[6, 7] have emphasized removal of the noncoronary leaflet as an integral part of valvuloplasty because of the fear that the prolapsed leaflet would cause aortic insufficiency. The present study suggests that excision of the leaflet is not uniformly necessary. Aortic insufficiency did not develop in any case in the present study. In fact, in one of the dogs (Case 10) some spreading of the aortotomy suture line occurred, leaving a gap at one end of the remaining two leaflets. This gap was covered by the prolapsed leaflet which had apparently resumed function.

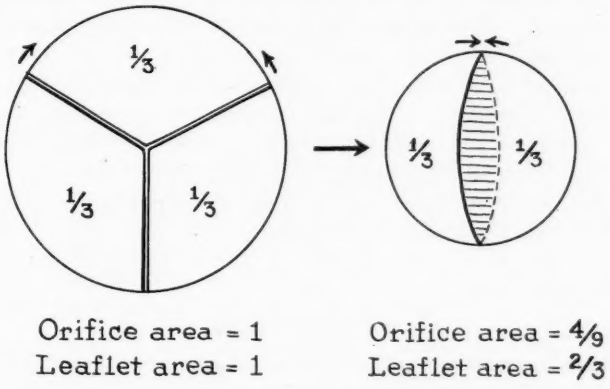


Fig. 7.—Geometric changes after bicuspidization.

The issue of whether or not the leaflet must invariably be removed would appear to be of more than academic interest in assessing the potential value of the described procedure in the treatment of clinical aortic insufficiency. In patients with regurgitation, the disparity between available leaflet and the orifice area seldom exceeds 25 per cent and is usually less. Restoration of valve competence would often not require such radical rearrangement of valve structure as with total bicuspidization. Rather, it would seem that treatment could consist of excision of a *portion* of the noncoronary annulus with retention of the tricuspid valve as suggested by Hufnagel.[9] Improvement in the $\frac{\text{leaflet area}}{\text{orifice area}}$ ratio would occur according to the amount of annular circumference excised and the reduction in orifice area could again be calculated from the formula $\frac{Ax}{Ay} = \left(\frac{Cx}{Cy}\right)^2$ as outlined above.

The operative procedure described would afford considerable versatility in the treatment of aortic insufficiency. According to the particular needs of the

case, one could excise a portion of the noncoronary annulus, excise the entire noncoronary annulus with defunctionalization of the valve, or excise both the annulus and leaflet. In the last case, excision of the leaflet can be done with the addition of only a few seconds to the operating time.

The operative procedure in the present study was done with inflow occlusion and hypothermia, necessitating haste and the routine use of resuscitative measures. Undoubtedly, a more desirable approach in clinical application would be the use of extracorporeal circulation with coronary perfusion.

SUMMARY

1. A simplified method is described for conversion of the aortic valve from a tricuspid to a bicuspid structure. Under conditions of hypothermia and inflow occlusion, the operative mortality is 10 per cent.

2. The noncoronary cusp can be completely or partially removed with this technique and the valve leaflet either defunctionalized (as was done in this series) or removed.

3. In dogs studied chronically, there was no evidence of physiologically significant aortic stenosis or aortic insufficiency. Left ventricular weights up to 5½ months postoperatively were within normal limits.

4. The geometric alterations produced in the aortic valve after bicuspidization are subjected to analysis. The applicability of this technique in the treatment of clinical aortic insufficiency is discussed.

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ARTERIOVENOUS FISTULA BETWEEN THE INTERNAL MAMMARY ARTERY AND VEIN FOLLOWING STAB WOUND OF THE CHEST

A Case Report

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PENETRATING wounds of the anterior wall frequently cause injury to the internal mammary and intercostal vessels since the ribs afford very little protection to these structures. Laceration of these vessels is followed by intrathoracic or extrathoracic bleeding. While penetrating injuries to other peripheral vessels may result in arteriovenous fistula or aneurysm, a review of the literature fails to reveal a report of an arteriovenous communication developing in the internal mammary vessels following trauma. Elkin and Warren,[1] in reviewing experience in 400 patients having arteriovenous fistulas incurred during World War II, encountered one communication between the internal mammary artery and innominate vein. Seeley and Elkin[2] have reviewed 106 instances of either arteriovenous fistula or false aneurysm occurring in 101 patients injured in the Korean War. Over 90 per cent of these occurred in the upper or lower extremities, with arteriovenous fistula occurring twice as frequently as false aneurysm.

Glenn and Steinberg[3] have reviewed the literature on arteriovenous fistula occurring incident to mass ligation of vessels following surgical procedures and report a case of arteriovenous fistula of the internal mammary artery occurring 2 years after radical mastectomy.

Arteriovenous fistulas may also be congenital in origin, but trauma is a much more common cause. A single case of congenital arteriovenous fistula of the internal mammary vessels has been reported by Wells and Hurt.[4]

The following case illustrates the occurrence of an arteriovenous fistula between the internal mammary artery and vein following a stab wound of the chest.

CASE REPORT

A 25-year-old Negro woman was admitted to Kansas University Medical Center on Jan. 28, 1958, with a history of having been stabbed in the right anterior chest 43 days previously by an assailant wielding a kitchen knife. She had received emergency treatment

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which included primary closure of the wound with sutures. Within a few hours, a painful swelling at the site of injury had developed for which an injection of an analgesic was given to relieve the pain.

A week later the skin sutures were removed. The pain and swelling still persisted and, 2 weeks following her injury, a physician incised the wound, thinking an abscess was present. Instead a jet of blood was released which sprayed the office wall. The bleeding was controlled with considerable difficulty by a combination of sutures and pressure bandages. Sufficient bleeding had occurred to make her noticeably weak for a few days.

Five days prior to admission she had consulted another physician who incised the mass and expressed several blood clots. Examination, upon admission to Kansas University Medical Center, revealed a nontender, fixed, pulsatile mass overlying the right parasternal region from the second to the fourth intercostal spaces. The mass measured 7 by 3.5 cm.

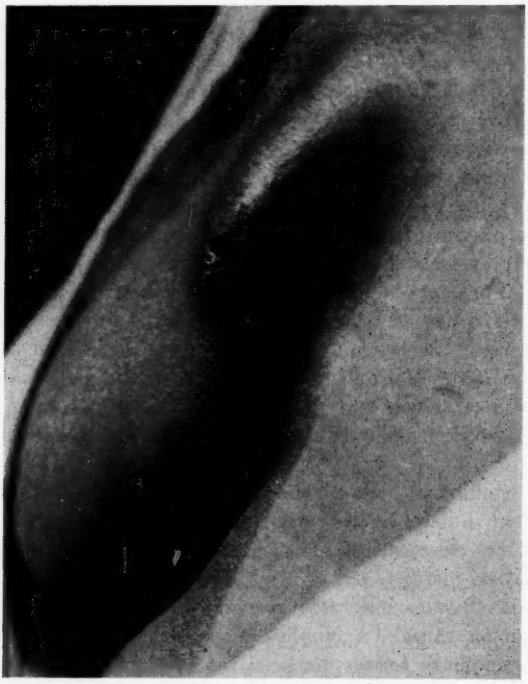

Fig. 1.—External surface of arteriovenous fistula between right internal mammary artery and veins shown by tangential view of the right parasternal area.

and projected 1.5 cm. beyond the surrounding skin. On the apex there was a crust at the site of the original stab wound and subsequent incisions (Fig. 1). A distinct bruit was heard over the mass.

The blood pressure was 140/70 mm. Hg; pulse 80; temperature 98.6° F.; hemoglobin 11.0 Gm.; white blood count 4,950; VDRL nonreactive. Chest roentgenograms did not disclose the mass and showed a normal cardiac silhouette.

On Feb. 1, 1958, a right parasternal elliptical incision was made around the mass. The internal mammary vessels were exposed over the second and fourth intercostal spaces without entering the thorax. The internal mammary vessels were enlarged and there was visible pulsation of the internal mammary vein proximally and distally to the mass. The internal mammary vessels were isolated and each was ligated in continuity in the second and in the fourth intercostal spaces to prevent subsequent hemorrhage. The mass was dissected free and was found to have a pedicle, consisting of an artery arising from the

internal mammary artery and venous channels joining the internal mammary vein (Fig 2). The vessels in the pedicle were individually ligated and divided and the wound was closed in layers.

The specimen consisted of an endothelial-lined cystic structure containing blood clots and an organizing thrombus. There were no postoperative complications.

COMMENT

In this case there was a penetrating injury of the anterior thorax, with laceration of the internal mammary vessels. An arteriovenous fistula resulted and this fistula was associated with a sac formed by the wall of the organizing hematoma. There was a continuous murmur, intensified during systole, and a

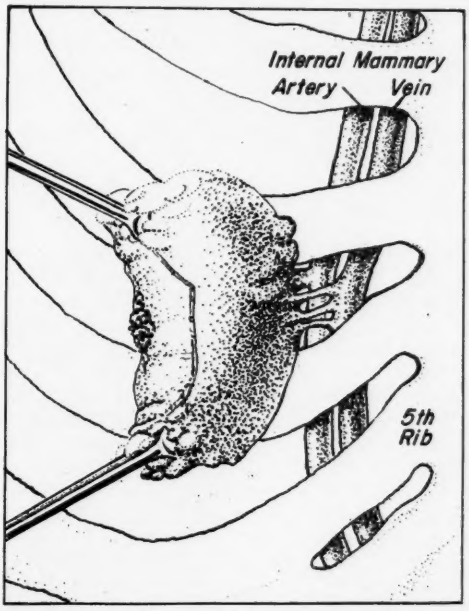

Fig. 2.—Diagram of arteriovenous fistula between right internal mammary artery and vein.

pulsatile mass present. There were no systemic circulatory manifestations present in this case. The dissected specimen, showing the three distinct venous channels and a single arterial vessel communicating with a common sac, confirmed the presence of an arteriovenous fistula. Surgical excision of the arteriovenous fistula with ligation of the involved vessels was curative.

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ASPHYXIATION DUE TO SIMULTANEOUS RUPTURE OF BRONCHUS AND PULMONARY ARTERY

Milton V. Davis, M.D., and Ben F. Mitchel, Jr., M.D.,* Dallas, Texas*

A NUMBER of accident victims are dead on arrival at hospitals, and an additional number die during attempts at resuscitation. In the following 2 patients, the cause of death was asphyxiation due to bleeding from a torn pulmonary artery into a torn bronchus. These cases are reported in explanation of some of these deaths and in the hope that, if this probability is borne in mind, an occasional patient may be saved.

CASE REPORTS

CASE 1.—F. W., a 9-year-old Negro girl, was admitted to the emergency room at Parkland Hospital (Dallas, Texas) shortly after 7:00 A.M. on Sept. 2, 1951. The child had been shot with a 32 caliber revolver accidentally and had either coughed or vomited a small amount of blood following the injury.

On examination, the child was semi-stuporous and pulse and blood pressure were unobtainable. A wound of entry was located in the right sixth intercostal space under the breast, and roentgenograms revealed a fracture and some metal fragments on the eighth right posterior rib and a hemopneumothorax. The bullet was lodged in the subcutaneous tissues at the level of the fourth posterior rib in the right posterior axillary line.

Initial treatment consisted of closed drainage of the right pleural space, and administration of 500 c.c. of lactate Ringer's solution and 1,000 c.c. of blood. The blood pressure rose to 90/60 mm. Hg, and 1,000 c.c. of blood drained into the bottle, as well as much air. A hemoglobin determination after resuscitation was reported as 14.2 Gm. per 100 c.c. of blood. The child's pulse, blood pressure, and general condition remained stable.

Because of the location of the wound, a diaphragmatic injury and, perhaps, a liver injury were suspected. A right thoracotomy and possible thoraco-abdominal exploration were recommended. In the operating room, induction of general anesthesia was accomplished without difficulty using cyclopropane and ether. As soon as the endotracheal tube was put in place, a gush of blood flowed out. The airway was suctioned, the right chest was opened rapidly and the hilum of the right lower lobe was first clamped with finger pressure and then with a noncrushing vascular clamp. This took approximately 2 minutes from the time of intubation. However, the heart was in total standstill, and massage and other measures failed to reinstate cardiac contractions.

At postmortem examination, the diaphragm was not perforated but there was an area where the bullet grazed the diaphragm. Immediately beneath this there was a subcapsular contusion of the dome of the liver with a slight tear in the capsule.

The right lung weighed 240 grams and there was evidence of fresh and old blood in the bronchi. A hole, measuring 4 mm. in diameter, was found on the inferior surface of the right lower lobe. The lobe was distended and firm. The lower portion of the middle lobe appeared similar. There were blood clots and some fresh blood seen throughout the

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bronchi on the right side. The bullet had apparently traversed a segmental bronchus to one of the basal segments of the right lower lobe and had also made a hole in the adjacent segmental pulmonary artery.

The left lung weighed 150 grams, contained a moderate amount of blood in the bronchi, and a large amount of frothy bloody material with a few clots.

CASE 2.—S. H., a 6-year-old white girl, was admitted to the emergency room at St. Paul Hospital (Dallas, Texas) a little after 1:00 P.M. on Dec. 29, 1958. The child had

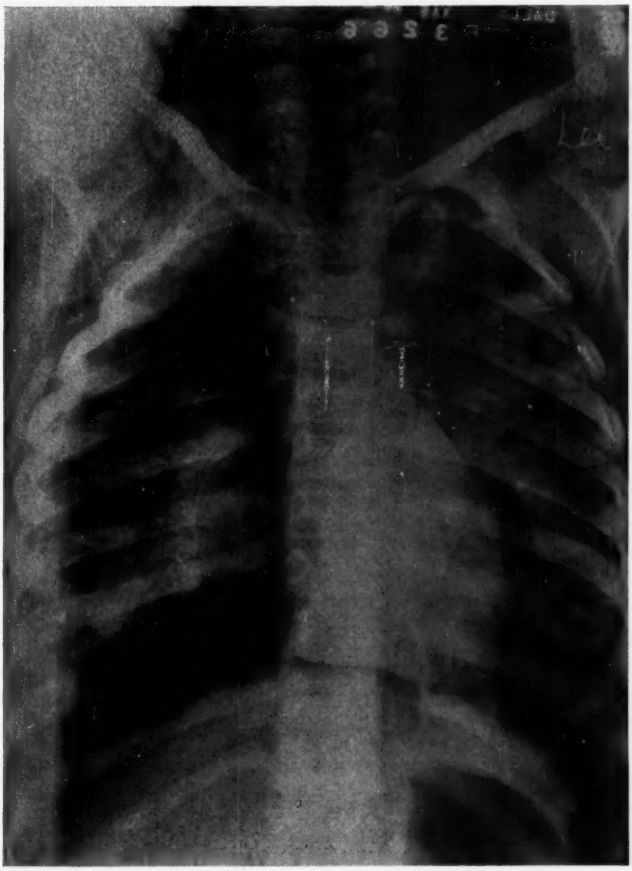

Fig. 1.—Roentgenogram taken with a horizontal beam, the patient lying on the right side, shows right tension pneumothorax, mediastinal shift, and mediastinal and cervical emphysema.

been struck by a vehicle while crossing the street. She reached the emergency room approximately 45 minutes after the accident.

Initial examination revealed an abrasion of the left temple, a comatose, nonresponsive child with no perceptible pulse or blood pressure, with the following salient points noted in the physical examination: The pupils were dilated, reacted to light, and appeared equal. There was moderate subfascial cervical emphysema bilaterally and moderate subfascial pectoral emphysema on the right. The breath sounds were absent over the right chest,

anteriorly and posteriorly. The skin was pale and veins appeared collapesed. Examination of the abdomen revealed no muscle spasm, masses, or distention. There were no palpable fractures. The right ulna gave evidence of an old injury.

Initial resuscitative measures included lactate Ringer's solution, via a plastic cannula into a saphenous vein, and oxygen.

Roentgenograms revealed massive mediastinal emphysema, right tension pneumothorax, retroperitoneal and cervical emphysema, and no evidence of fluid in the right chest (Fig. 1).

A diagnosis of probable rupture of the right main bronchus was made and two intercostal drainage tubes were placed in the right pleural space and attached to a water-seal drainage system. The child's condition immediately improved and, by the time the second tube was put in place, the blood pressure had risen to 90/60 mm. Hg and remained stable. The cervical emphysema began to recede. In addition, the previously noted comatose state was apparently due in part to asphyxia and tension pneumothorax because the child waked up, was responsive, and able to cooperate following intubation of the chest. It was noted that with every exhalation a large amount of air would pass into the drainage bottle, suggesting a wide open tear in either lung or bronchus. The decision was made to subject the child to rapid general anesthesia, bronchoscopy to confirm the diagnosis of ruptured bronchus, and thoracotomy for repair. A Levin tube was passed into the stomach and a moderate amount of air and about 15 c.c. of gastric juice were aspirated. No blood or bile was obtained.

While preparations were being made in the operating room to receive the patient, she either coughed or vomited a small amount of blood. It was the impression of the nurse that this had been vomited. This was followed by a 30-second period of cyanosis, which cleared with oxygen. After this episode, multiple râles were heard in the left lung suggesting the need for endotracheal suction. It was planned to accomplish this under anesthesia.

Just before the patient was to be transferred from the emergency room table to the carriage to be moved to the operating room she suddenly died.

At the postmortem examination the chest was opened under water. There was no pneumothorax on the left side. The right lung was completely collapsed. The peritoneal cavity was opened under water and a few bubbles of air escaped, estimated at only several cubic centimeters.

No broken ribs were found. There was very severe mediastinal emphysema and significant interstitial hemorrhage in the region of the thymus gland and both hilar pleural reflections, extending into the pulmonary ligaments. There was complete transverse severance of the right main bronchus 1.2 cm. from the carina on the cartilage side, with a linear tear, in the membranous portion which extended to within 8 cm. of the carina. The two ends of the bronchus were separated by 2.5 cm. A stretching type attenuation of the apical-anterior segmental branch of the pulmonary artery was noted opposite the tear in the bronchus, with a small hole which apparently had leaked directly into the torn bronchus. The chest cavity on the right now contained approximately 400 c.c. of blood and the stomach contained 250 to 300 c.c. of blood. There were a few clots, a large amount of fresh blood, and some bloody froth in the entire tracheobronchial tree. The diaphragm, spleen, liver, and all the abdominal organs were intact and there was no hemorrhage below the diaphragm.

SUMMARY

Two cases are reported in which concomitant injuries to bronchus and pulmonary artery occurred. The clinical course and postmortem findings indicate that the mode of death in each case was asphyxiation due to aspirated blood, the source of which was a tear in the pulmonary artery immediately adjacent to a tear in a bronchus. In the first case, the injury was caused by a gunshot wound. In the second case, the injury was caused by blunt trauma, the child having been struck by an automobile.

BOW MATTRESS SUTURE FOR CHEST CATHETERS

James Bernard Seaman, M.D., Tyler, Texas*

WE PROPOSE a method of prevention of air and fluid leakage about a chest catheter in place, and through the tube wound after the catheter has been withdrawn.

No one can deny that lack of control of the situation can add to pleural space problems such as pneumothorax and empyema, especially when negative pleural space pressure may be inordinately high, and add to loss of fluid into a dressing with invitation to infection.

Since 1947 we have seen many methods of control used. The present technique has been employed for many months and has been adopted as a standard part of our regimen.

It consists essentially of a horizontal mattress suture of 0 cotton (Fig. 1) through the skin and subcutaneous tissues with the loop or bight around the catheter and with the suture ends normally located cephalad to facilitate later extraction of the catheter by an assistant, and tying of the knot by the operator. This suture may be applied either before or after the catheter is placed in position in the chest wall.

With the catheter in place, a friction knot (first knot or double overhand of a surgeon's knot) is then tied. A double bow knot is then tied securely with the suture ends longer than the bows. This serves then as a purse-string suture through the soft tissues, about the catheter, which effectively seals against movement of air or fluid.

A small clamp of the mosquito type is then placed across the bows and suture ends until the time of securing the wound dressing. The clamp is lifted to make the suture taut alongside the catheter and narrow adhesive tape is placed around the catheter in spiral fashion securing the suture material to the catheter. The catheter is thus doubly secured and tugging on the catheter or connecting hose serves only to tighten the soft tissues about the catheter. Being prudent, we attain additional protection with tape over the skin, onto the dressing, and onto the catheter.

In removing the catheter one simply grasps the suture (bows and ends), unwinds the spiral tape, unties the bow as when untying shoe strings, and

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loosens the friction knot if necessary with a clamp. An assistant extracts the catheter on command, and the operator promptly pulls the friction knot tight and completes a surgeon's knot.

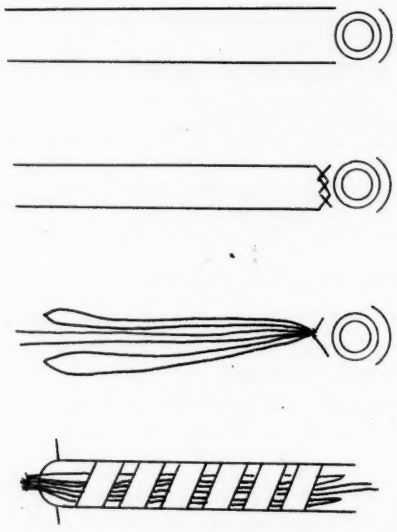

Fig. 1.

We have experimented with many methods and are of the opinion this is the best. It may be original with us. There has been no fluid or air exchange about the catheter, no tissue necrosis, and no early or late abscess of the chest wall. If no assistant is available the routine may be followed successfully by one individual. There is one precaution—if one is forced to use a soft catheter one must be careful not to obstruct the lumen when tying the friction knot.

Announcements

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The Fortieth Annual Meeting of The American Association for Thoracic Surgery will be held May 11, 12, and 13, 1960, in Miami Beach, Florida. Headquarters will be the Deauville Hotel.

Requests for Hotel Reservations

These should be mailed directly to Mrs. Mildred Sander, Reservation Manager, Deauville Hotel, Miami Beach, Florida. Please mention this Association, the type of accommodation desired, the date, and approximate hour of arrival and departure. If accommodations are desired elsewhere please communicate directly with the hotel of your choice.

Material for the Program

SCIENTIFIC PAPERS.—Abstracts of all papers proposed for presentation at the 1960 meeting *must be received on or before* **November 15, 1959,** otherwise they will not be considered by the Program Committee. These should be labeled "For Thoracic Surgery Forum" or "For Regular Program" depending upon the nature of the subject matter, in the same manner as in previous years. They should contain from 200 to 250 words that accurately reflect the content of the completed paper.

Six, repeat, six clearly legible copies of *each* abstract must be sent to Miss Ada Hanvey, Administrative Assistant, The American Association for Thoracic Surgery, 308 Carondelet Building, 7730 Carondelet Avenue, St. Louis 5, Missouri.

Essayists selected for the program are reminded that papers presented at the meeting *must* be handed to the secretary *immediately* after their presentation. If they are not ready at that time there is a chance that they will not be published in THE JOURNAL OF THORACIC AND CARDIOVASCULAR SURGERY.

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee *not later than* **November 15, 1959,** otherwise the application will be deferred for consideration until the 1961 meeting.

Applicants must be sponsored by three Active or Senior Members of the Association. In addition to the signature on the application form, the sponsors will forward a *separate* letter concerning the applicant directly to:

Frank Gerbode, M.D.
Chairman of the Membership Committee
Stanford University Hospital
San Francisco 15, California

Sponsors are reminded that *new* letters of recommendation must be forwarded to the Chairman of the Membership Committee should their applicants be held over for reconsideration a *second year.*